Science Indicators 1980

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Science Indicators 1980

Report of the National Science Board 1981

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Letter of Transmittal

March 31, 1981

My Dear Mr. President:

I have the honor of transmitting to you, and through you to the Congress, the Thirteenth Annual Report of the National Science Board. The report was prepared in accordance with Section 4(j) of the National Science Foundation Act, as amended.

Science Indicators—1980 is the fifth in a series of the Board's annual reports to be devoted to the quantitative assessment of the status of science and technology in the United States. Science and technology pervade every aspect of our daily lives and will continue to have an increasingly important role in the strength and welfare of the Nation. Through the *Science Indicators* reports, the Board hopes to contribute to a broad understanding of the scientific and technological enterprise itself and of its impact on society.

This report analyzes U.S. science and technology per se and in relation to the efforts of other major countries performing research and development. It also provides information on public attitudes and expectations concerning science and technology, as well as a description of selected recent research accomplishments.

I hope that this report, and the discussions and analyses it stimulates, will be of particular interest to you and to the science and technology policy and research communities.

Respectfully yours,

Lewis M. Branscomb

Lewis M. Branscomb
Chairman, National Science Board

The Honorable
The President of the United States
The White House
Washington, D.C. 20500

Contents

Introduction

In 1969, the National Science Board began to report annually to the Nation on the state of the U.S. scientific endeavor and in 1973 issued the first *Science Indicators* report. *Science Indicators—1980* is similar to its four predecessors in presenting quantitative indicators of the many characteristics of organized science and technology, accompanied by trend analyses and interpretations.

The quantitative measures covered in *Science Indicators—1980* are not intended to replace the judgment of policymakers who are faced with specific scientific and technical issues. Rather, the material presented here provides a broad information base to stimulate the planning, debate, and negotiation which surround such issues. Taken individually, sets of data generally are not sufficiently definitive in describing certain aspects of science and technology, but when considered together as multiple indicators of a phenomenon, these data sets permit more lucid comprehension and broader perspectives. And as indicators, they are *indirect* reflections of performance, behavior, or status.

A comprehensive appraisal of the American science and technology system should encompass its principal components: the scientists and engineers who create and apply new knowledge; the solutions of problems in specific areas of investigation; the sophisticated equipment and instrumentation by which powers of observation are vastly expanded and which serve as the vehicles for the implementation of research results; the relation of the endeavor to the Nation's economic and social well-being; and many others. A complete assessment requires examining the entire system, both from within and from outside the scientific and technological establishment. Such an effort involves many approaches, diverse data sources, and a wide range of analytical and statistical methods. Unfortunately, since all the needed tools have not yet been developed, the creation of increasingly effective methodologies also brings about accompanying research problems of major proportions.

Analysis of the status of U.S. science and technology represents a challenge because of the complexity of the enterprise itself, its multiple sources of support, its diverse performance settings, its relation to scientific and technological developments across the world, its dispersed loci of decision-making, and its multiplicity of purposes. Great interest exists for developing specific measures of the value and impact of science and technology, particularly of investment in research and development, but only limited methodologies exist to provide such measures. Identifying the unique impacts of scientific and technical activities is problematic because of their interaction with major factors affecting the economy and other aspects of society.

Because the substantive aspects of science and technology are not easily captured by quantitative indicators, this report contains a new, completely descriptive chapter entitled "Advances in Science." This chapter attempts to convey the process and significance of research by describing a few illustrative areas: astronomy, cognitive science, information flow in biological systems, catalysts and chemical engineering, and communications and electronics. These five topics are neither representative of the extremely wide scope of modern research activity, nor are they necessarily the most important areas being investigated; instead, they exemplify recent trends in the cumulative development of a few sample areas.

In *Science Indicators—1980*, the National Science Board returns to the earlier pattern of including a chapter on public attitudes toward scientific and technological activities. This chapter presents the results of a major new survey conducted in late 1979 expressly for this report, and contains also the results of other related foreign and U.S. studies. For the first time, the responses of a subgroup labeled "the attentive public toward science and technology" are available separately. This group consists of those whose knowledge, interests, and information-acquisition habits toward science and technology are markedly pronounced. Consequently, their attitudes are of special importance to those policymakers needing information about the informed public, who are more likely to take an active role in such issues.

Science Indicators—1980 is one of several major background sources for the development of science and technology policy. In addition to a continuing flow of other relevant reports from NSF and other agencies and organizations, the National Science Foundation has developed a three-pronged approach to the assessment of science and technology. The biennial *Science Indicators* series of the National Science Board is complemented by the congressionally mandated *Five Year Outlook Report* and the *Annual Science and Technology Reports*. The *Outlook* report addresses the intellectual, material, personal, and social advances to which American

science can, and does, contribute. The *Annual Science and Technology Reports* review recent decisions, actions, and program initiatives within the Federal Government which involve scientific and technological activities, and examine selected current and emerging issues and problems that require attention in the near future.

The reports in the *Science Indicators* series have changed gradually, as the information needs of their audience have become clearer and as new data, methodologies, and analyses have been developed. Progress in this evolution results from the contributions of those individuals who bring their expertise and innovative ideas to fruition within the purposes and scope of the *Science Indicators* concept. Numerous reviews and the feedback from users of these reports continue to illustrate the need for better indicators, but specific suggestions have been sparse. Consequently, the National Science Foundation supports research to stimulate developments in this area, with the expectation of improving future *Science Indicators* volumes. In addition, a reader response card accompanying the report permits recommendations of new indicators and evaluations of the present report.

As can be seen from the following acknowledgments and Appendix II, many individuals aided in the preparation of this report. The overall responsibility was that of the National Science Board, assisted by a special committee of its members. Responsibility for preparation of the report was assigned to the Directorate for Scientific, Technological, and International Affairs (STIA). The manuscript was produced by the Division of Science Resources Studies (SRS). While the SRS Science Indicators Unit staff worked exclusively on the report and its underlying research, other SRS staff aided in the manuscript preparation.

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The draft manuscript was produced by the Division of Science Resources Studies under the guidance of:

Dr. Charles E. Falk, Director
Dr. Robert R. Wright, Head, Science Indicators Unit

The manuscript was written by the following staff of the Division of Science Resources Studies:

Dr. Donald E. Buzzelli, Science Indicators Unit
Mr. Gerard R. Glaser, Jr., Science Indicators Unit
Ms. Jennifer Sue Bond, Science Indicators Unit
Mr. Michael F. Crowley, Scientific and Technical Personnel Studies Section

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The Board is also grateful to the special consultants and to those who reviewed the various chapters of *Science Indicators—1980*, all of whom are listed in Appendix II.

Committee on the Thirteenth National Science Board Report

Dr. Joseph M. Pettit, *Chairman*, President, Georgia Institute of Technology

Dr. Eugene H. Cota-Robles, *Vice Chairman*, Professor of Biology, University of California at Santa Cruz

Dr. Michael Kasha, Distinguished Professor of Physical Chemistry, Florida State University

Dr. Homer A. Neal, Dean of Research and Graduate Development and Professor of Physics, Indiana University

Dr. David V. Ragone, President, Case Western Reserve University

Dr. Saunders Mac Lane, former member of the Committee, Max Mason Distinguished Service Professor of Mathematics, University of Chicago

Chapter 1
International Science and Technology

International Science and Technology

INDICATOR HIGHLIGHTS

- The United States has the greatest number of R&D scientists and engineers (S/E's) and the highest proportion of such S/E's in the labor force of any country except the Soviet Union. From the late 1960's through the early 1970's, the ratio of R&D scientists and engineers to the labor force declined in the United States. Though the ratio has increased slightly in the past few years, it has not regained its former level. In most other countries, especially the Soviet Union, Japan, and West Germany, this ratio steadily increased over the same period. (See pp. 4-5.)

- Total national R&D expenditures by all sectors of the United States exceeds that of France, West Germany, and Japan combined—$48.3 billion in 1978, for example, compared with $46.5 billion for the other three countries. When the size of the economy is taken into consideration, the 1978 U.S. R&D-to-GNP expenditure ratio of 2.23 is higher than that of Japan (1.93) but lower than that of West Germany (2.37). For most industrialized countries, these ratios seem to have remained relatively constant since the mid-1970's. The U.S. ratio peaked in 1964 at 2.96 and generally declined through the 1970's. It began rising again in 1979 and is expected to reach 2.37 in 1981. See pp. 7-8.)

- Over the past two decades, West Germany and Japan have had by far the highest ratios of national civilian R&D expenditure to GNP, reaching 2.18 and 1.87, respectively, by the late 1970's. This concentration in civilian R&D may have enabled the Japanese and West Germans to increase their productivity and to be more competitive in world trade. Throughout the 1960's, the U.S. ratio of civilian R&D to GNP increased, and after a temporary decline in the early 1970's, surpassed its former level, reaching an estimated 1.66 in 1981. (See pp. 8-10.)

- Investments in R&D and technological innovation have positive long-term effects on productivity and economic growth. Over the past decade, the United States has experienced slower growth rates in manufacturing productivity than have most industrialized countries. From 1970 to 1980, productivity (measured by output per worker-hour) in manufacturing industries in the United States increased 28 percent, contrasted with 102 percent in Japan, and about 60 percent in both France and West Germany. In 1980, however, overall productivity levels in France and West Germany were still over 10 percent lower than that of the United States; Japan's productivity level was over 30 percent lower than the U.S. productivity level for the whole economy. (See pp. 13-15.)

- The United States is one of the few OECD countries that has significantly and consistently increased public financing of energy R&D since the energy crisis arose in 1973. U.S. Federal energy R&D funding rose from $0.6 billion in 1973 to $3.6 billion in 1980. However, it should be noted that the energy portion of U.S. Government R&D funding was lower, initially, than that of Japan and many European countries (See p. 10.)

- The U.S. proportion of the world's scientific literature found in over 2,100 highly-cited and influential journals was stable at about 37 percent over the 1973-79 period, indicating that U.S. scientists are internationally competitive in their research outputs. Despite declines in the U.S. share in six out of eight individual fields, the number of U.S. articles in the large and rapidly developing fields of biomedicine and clinical medicine increased, helping to maintain the overall portion of world scientific literature. (See pp. 16-17.)

- Domestic patenting by U.S. inventors declined 26 percent from 1971 to 1978 while patenting in the United States by foreign inventors rose 11 percent. Much of this increase was due to the number of patents issued to Japanese inventors; from 1971 to 1978, the number of patents granted to inventors from this country rose 71 percent. More than half of all patents granted to foreign inventors by the United States in 1978 were assigned to inventors from Japan and West Germany (28 percent and 24 percent, respectively). (see pp. 18-21.)

- The orientation of U.S. innovations has been different from that of other regions. In a sample

of innovations introduced in 1945-74, the largest portion (40 percent) of the U.S. innovations were perceived as laborsaving, compared to a heavy emphasis on materialsaving and capital-saving innovations by Europe and Japan (58 percent and 41 percent respectively). American business now confronts world markets that place a greater value on the conservation of energy, materials, and capital. As a result, some analysts believe that the traditional U.S. emphasis on laborsaving innovations may no longer be as relevant or in demand in world trade as are the European and Japanese capitalsaving and materialsaving innovation emphases. (See pp. 22-25.)

- The United States sells about nine times more technology than it buys. Total U.S. receipts of payments for royalties and fees increased 258 percent from 1967 to 1978, reaching $5.2 billion; over 80 percent of U.S. technical expertise transferred through licensing agreements was to industrialized nations. U.S. firms have transferred technology primarily via their foreign affiliates, and the increase in the number of U.S. subsidiaries (especially R&D-intensive firms) that are manufacturing new foreign products is accelerating significantly. From 1975 to 1979, the amount of R&D conducted abroad by U.S. affiliates increased 88 percent, reaching a level of $2.7 billion, which is equal to 11 percent of U.S. industry's company R&D funds. (See pp. 25-29.)
- The United States enjoys a favorable balance of trade in R&D-intensive manufactured products with all its major trading partners except West Germany and, in particular, Japan. The U.S. trade balance with Japan in R&D-intensive manufactured products has been negative since the mid-1960's, but the deficit has increased greatly since 1974 and was $4.3 billion in 1979. Although the United States still has an overall competitive advantage in R&D-intensive products and technical information, there has been some erosion of that position; the U.S. share of the world market in these products dropped from 31 percent in 1962 to 27 percent in 1970, and then to 21 percent in 1977. (See pp. 30-34.)
- Japan, West Germany, and the Soviet Union have stressed science and mathematics literacy in their secondary schools to a greater degree, and for a far greater cross section of students, than have the United Kingdom and United States, thereby giving substantial proportions of their populations scientific and technical backgrounds. At higher education levels, however, U.S. graduates in S&T fields are believed to receive more flexible and broad-based theoretical educations than their Soviet counterparts. (See pp. 6-7.)
- U.S. universities and colleges are contributing significantly to world S&T capabilities and colleges. During the academic year 1979-80, the number of foreign students enrolled in U.S. universities and colleges rose to a record level of 286,340—more than eight times the number of foreign students in 1954-55. About 55 percent of all foreign students in the United States are studying in scientific and technical fields, almost half of them in engineering programs. The number of foreign students studying mathematics and computer sciences expanded rapidly from only 436 in 1954-55 to almost 15,400 in 1979-80. There are currently over 10 times the number of foreign engineering students in the United States as there were in the mid-1950's. In 1979, foreign students received 21 percent of all U.S. doctoral degrees awarded in S&T fields, and nearly half of all engineering doctorates. While the number of foreign students in the United States continues to grow, their total still represents only a small fraction of all students enrolled in higher education. (see pp. 39-41.)

R&D in diverse fields and from many countries supports development of the knowledge, skills, and technology necessary to face increasingly complex national and international problems. The impact of science and technology on the economy and on society transcends national boundaries. Because of the global nature of science and technology and because of the importance of taking a broad perspective, this chapter examines U.S. science and technology activities in an international context.

In the 1960's many European nations were concerned about a perceived technology gap between Europe and the United States. Today, the situation has changed somewhat, with concern often being expressed over the technological position of the United States. Many nations have increased their scientific and technological capabilities, resulting in growing economic competition from abroad in technological products and services. However, greater opportunities for increased international interac-

tion and cooperation also have been made possible by increased foreign S&T capacities.[1]

Cross-country comparison is one method to evaluate the status of U.S. science and technology. The first section of this chapter presents comparisons of the scientific and technological activities of industrialized nations and discusses the interaction of R&D resources, other resources, and economic growth.

The chapter's second section examines indicators of R&D outputs. It is difficult to separate the results of R&D and measure them quantitatively, but an effort is made to do so here in two main areas. Because scientific findings normally are reported in publications, scientific literature is one of the most direct forms of scientific output and is examined here as a valuable indicator. Patent data are presented as an indicator of inventive activity and commercial interest in foreign markets. Countries are not limited to the use of their own R&D investments. A great deal of technical know-how flows across national borders. In fact, the ability to effectively utilize and apply the technical outputs of other nations is extremely important, as exemplified by Japan's experience. The third section of the chapter describes this flow and presents indicators of the magnitude and channels of technology transfer. Rising costs of research and increasing scientific capabilities of other nations make international cooperation more advantageous. Furthermore, many scientific phenomena can be examined only through collaborative efforts among nations. The final section of this chapter focuses on U.S. involvement in international scientific cooperation.

Differences in definitions, concepts, data collection methodologies, and statistical reporting procedures exist from country to country. Because of these limitations, attention should be paid primarily to large changes and trends. However, several international organizations such as the Organisation for Economic Cooperation and Development (OECD) and the United Nations Educational, Scientific, and Cultural Organization (UNESCO) have done much to institute uniform definitions and standards.

R&D RESOURCES OF VARIOUS COUNTRIES

What is an adequate level of R&D investment? There is no known optimal national level, but international comparisons can shed light on the question of what is an appropriate national R&D allocation. Research and development is not conducted in a vacuum; it has an influence on economic growth and in turn is affected by economic conditions. This section presents national comparisons of R&D investments—in terms of both technical personnel and expenditures. It also discusses the role of R&D in economic growth. Increased research spending does not automatically increase the world's scientific knowledge nor does it ensure greater economic growth. However, scientific personnel and R&D expenditures reflect national scientific and technical capabilities and are viewed as an important investment in the future.

Scientific and Technical Personnel

The scientific and technical work force is one of the most important components of any country's S&T system; properly trained and innovative scientists and engineers help to ensure that technological efforts are effective. While data on total scientists and engineers are available for the United States, no comparable data exist for most other countries. However, information on R&D scientists and engineers is available and shows that, in absolute numbers, the United States has a far greater number than do most other countries (645,000 in 1980).[2]

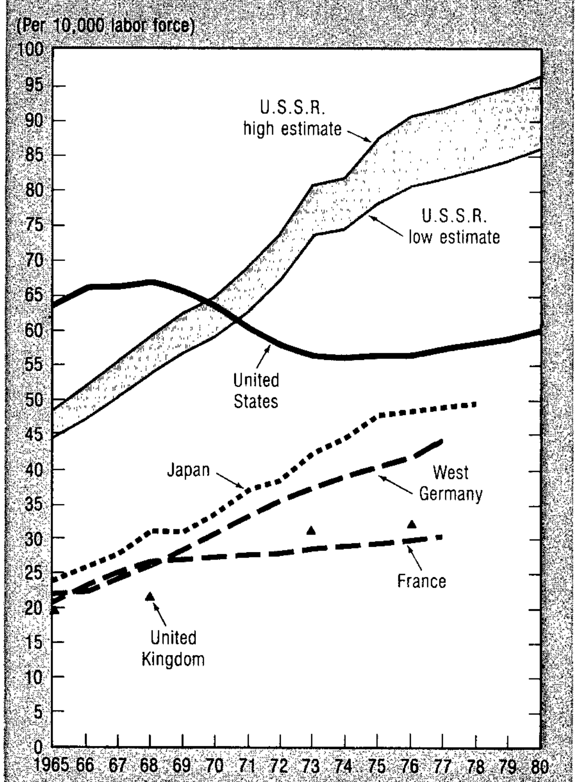
One way to compare the relative size of the S/E work force in each country is to examine the number of scientists and engineers engaged in research and development as a proportion of the labor force. Figure 1-1 shows that the United States has the highest ratio of any large industrial country except the Soviet Union. In the United States, during the late 1960's and early 1970's, the absolute number of S/E's engaged in research and development declined, resulting in a 16-percent drop in this ratio from 1968 to 1974. Since then, there has been positive growth in the number of S/E's, especially in the life sciences, the environmental sciences, and the mathematical and computer sciences.[3] The ratio increased slightly to its 1980 level of about

[1] A recent report of a 3-year international project of 19 OECD member nations examines the future problems and development of advanced industrial societies in harmony with that of developing countries. It predicts keener competition between industrialized countries and outlines the need for increased cooperation in facing our shared problems. See Interfutures, *Facing the Future* (Paris: Organisation for Economic Co-operation and Development, 1979), pp. 334-394.

[2] These international comparisons of R&D scientists and engineers are in terms of full-time-equivalent work in R&D.

[3] *National Patterns of Science and Technology Resources, 1980*, National Science Foundation (NSF 80-308), p. 8.

Figure 1-1
Scientists and engineers[1] engaged in R&D per 10,000 labor force population by country



[1]Includes all scientists and engineers on a full-time-equivalent basis (except for Japan, whose data include persons primarily employed in R&D, and the United Kingdom, whose data include only the Government and industry sectors).

NOTE: A range has been provided for the U.S.S.R. because of the difficulties inherent in comparing Soviet scientific personnel data.

REFERENCE: Appendix table 1-1. Science Indicators—1980

60 R&D scientists and engineers for every 10,000 people in the labor force.

While the concentration of R&D scientists and engineers in the U.S. labor force declined during the early 1970's and has not regained its former level of the late 1960's, most other countries increased this proportion throughout the period. The Soviet Union, Japan, and West Germany showed particularly large increases in their ratios.

There are numerous problems involved in comparing U.S. and Soviet scientific personnel statistics because the accuracy and comparability of the Soviet data are difficult to assess. Therefore, a range has been provided between high and low estimates. Attempts have been made here to present figures for the Soviet Union corresponding to U.S. definitions of full-time-equivalent scientists and engineers rather than rely on Soviet definitions.[4] The Soviet ratio of R&D scientists and engineers to the total labor force surpassed the U.S. ratio sometime in the late 1960's or early 1970's and in 1980 is estimated to be between 86 and 97 S/E's engaged in R&D per 10,000 individuals in the labor force compared to 60 in the United States.

The size of the R&D labor force is only an approximate measure of a nation's R&D capacity. It does not address such factors as the level of sophistication or specialization, utilization, or productivity of a country's R&D personnel.[5] Level of both general and advanced scientific and technical education is another factor influencing a nation's S&T capabilities and has been the concern of several countries, including the United States. Several studies[6,7] were conducted to determine the adequacy of S/E training in various countries. From these studies, it appears that Japan, West Germany, and the Soviet Union have stressed scientific and mathematical proficiency in their secondary educational institutions to a greater degree than have the United Kingdom and United States, thereby giving substantial proportions of their populations scientific and technical training.

Comparisons of the capabilities of U.S. and U.S.S.R. scientific and technical personnel and S&T educational training have been the focus of

[4]These estimates have been developed for the *Science Indicators* series. See Robert W. Campbell, *Reference Source on Soviet R&D Statistics 1950-1978*, National Science Foundation, 1978; Robert W. Campbell, *Soviet R&D Statistics, 1977-1980*, National Science Foundation, 1981. The latter describes differences in methodology between estimates recently developed by Louvan E. Nolting and Murray Feshbach, "R&D Employment in the U.S.S.R.—Definitions, Statistics and Comparisons" *Soviet Economy in a Time of Change*, vol. 1, Joint Economic Committee, U.S. Congress, October 1979. The Nolting-Feshbach estimates are more conservative and closer to the official figures published by the Soviet Union. They are 20- and 36-percent smaller than Campbell's low and high estimates, respectively. Nonetheless, both sets of estimates follow the same basic trends and still exceed the U.S. ratios.

[5]Many of these factors are discussed for the United States in the Scientific and Engineering Personnel chapter of this report.

[6]*Science and Engineering Education for the 1980's and Beyond*, prepared by the National Science Foundation and the U.S. Department of Education, 1980.

[7]For the British findings, see *Engineering Our Future: Report of the Committee of Inquiry into the Engineering Profession* (London: Her Majesty's Stationery Office, 1980). This report is commonly referred to as the "Finniston Report" after the Commission's chairman, Sir Montague Finniston.

several recent studies[8] that show that the Soviet Union has placed a great deal of emphasis on scientific and technical training at all levels of education. The studies indicate that Soviet secondary school graduates have a greater preparation in mathematics and science than do U.S. high school students, although there is evidence of some problems with the quality of Soviet instruction and facilities, particularly in the rural areas. For instance, high student/teacher ratios and problems of accessibility to good laboratories exist.[9]

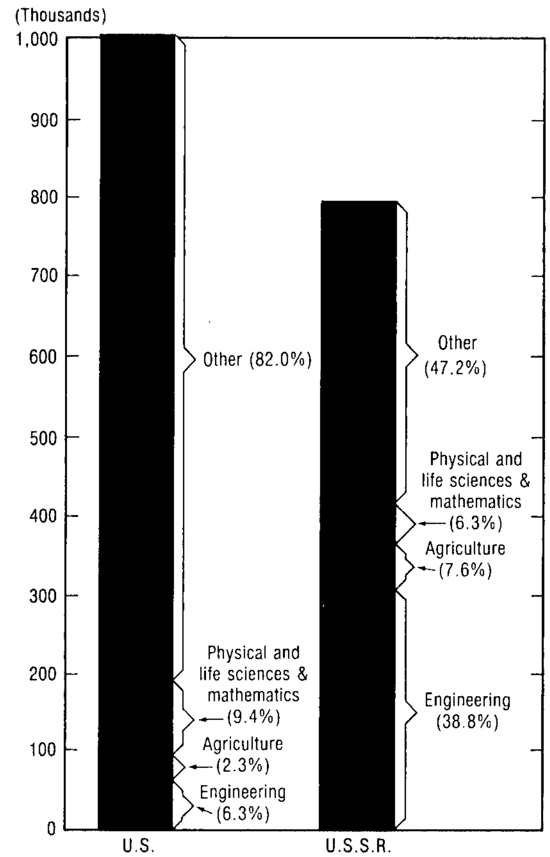
Figure 1-2 compares, by major field of study, U.S. bachelor's degrees and U.S.S.R. diplomas conferred in 1979. It demonstrates that although the United States graduated over 27 percent more students, only about 18 percent of U.S. students received their bachelor's degrees in science and engineering fields (179,700) compared to 53 percent (416,900) in the Soviet Union. The Soviets conferred 132 percent more S/E bachelor's degrees than did the United States. The United States graduated about twice as many specialists in the physical and life sciences and mathematics as the Soviet Union, while it graduated only about one-fifth as many engineers. Approximately one-third of the Soviet engineering graduates were enrolled in part-time programs which may provide lower quality training than full-time programs; even so, the difference in the number of engineering graduates is substantial.[10]

Appendix table 1-2 presents data on the relative proportions of the populations of these two countries receiving S&T training. It shows that in 1979, 9 percent of the 23-year-olds in the Soviet Union graduated in science and engineering fields—or roughly twice the corresponding proportion in the United States (4 percent). By examining the total number of specialists with advanced degrees in engineering and the sciences (Candidate of Science or Doctor of Science in the Soviet Union and doctoral degrees in the United States), it can be seen that the United States leads the Soviet Union only in the social sciences and humanities. The Soviet Union has twice the number of specialists with advanced engineering degrees as does the United States.[11]

These trends in scientific and technical training underlie the wide differences between the two countries in the proportion of R&D scientists and engineers in the labor force. However, Soviet graduate training programs are considered to be more nar-

Figure 1-2

U.S. bachelor's degrees and U.S.S.R. diplomas conferred by major field of study: 1979



REFERENCE: Appendix table 1-2.

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[8]Nicholas DeWitt, *Summary Findings: The Current Status and Determinants of Science Education in Soviet Secondary Schools* (Washington, D.C.: National Research Council, 1980); Roger K. Talley, *Soviet Professional Scientific and Technical Manpower*, Defense Intelligence Agency, 1975, pp. 9-36; Catherine P. Ailes and Francis W. Rushing, *Training and Utilization of Scientists, Engineers, and Technicians: U.S. and U.S.S.R.* (Washington, D.C.: SRI International, 1981) and Catherine P. Ailes and Francis W. Rushing, *Summary of Soviet Report on the Training and Utilization of Scientific, Engineering and Technical Personnel* (Washington, D.C.: SRI International, 1980).

[9]Ibid., pp. 1-5.

[10]Appendix table 1-2; Catherine P. Ailes and Francis W. Rushing, *A Summary Report on the Educational Systems of the United States and the Soviet Union: Comparative Analysis* (Washington, D.C.: SRI International, March 1980), p. 14. Not only are there fewer engineers in the United States than in the U.S.S.R., but the current supply of U.S. engineers is insufficient to meet the market demands. See the Personnel chapter for extended treatment of this topic.

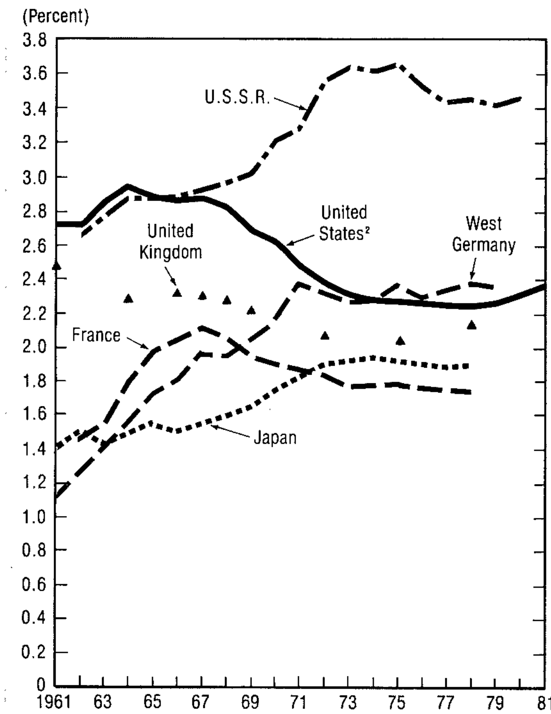
[11]Ibid., pp. 14-17.

rowly specialized, oriented toward the specific needs of research institutes, and geared toward applied science, while U.S. graduates receive a broader based and more flexible theoretical education.[12] Moreover, a third of all nondoctorate U.S. scientists and engineers have increased their skills through further formal training in master's degree programs while the Soviet Union does not have such programs.[13] Therefore, it may be that the U.S. specialists, although fewer in number, are better prepared to deal with future problems and goals.

In terms of the general population, however, the scientific and mathematical competence of nonscientists in the United States is relatively lower than in many other countries, including West Germany, Japan, and the Soviet Union. This deficiency may be important as U.S. society and institutions face increasingly complex technical issues and rely on more advanced technologies. In the Soviet Union, Japan, and West Germany, national policies promote the training of S/E's in greater numbers than are expected to engage in scientific and engineering professions; consequently, in the former two countries, in particular, managerial positions in both government and industry are heavily populated by people with engineering degrees.[14] For instance, in Japan, about half of both the senior civil service and industrial directors hold degrees in engineering or related subjects.[15] In the United States, engineers are more frequently managers than are scientists in other S&T fields. In 1978, about 30 percent of engineers were in management and administration. Nonetheless, engineers represent only about 4 percent of all managers and administrators in the total economy.[16]

Figure 1-3

National expenditures for performance of R&D[1] as a percent of gross national product (GNP) by country



[1]Gross expenditures for performance of R&D including associated capital expenditures, except for the United States where total capital expenditure data are not available.

[2]Detailed information on capital expenditures for research and development are not available for the United States. Estimates for the period 1972-80 show that their inclusion would have an impact of less than one-tenth of one percent for each year.

NOTE: The latest data may be preliminary or estimated.

REFERENCE: Appendix table 1-3. Science Indicators—1980

Expenditures for Research and Development

Large investments in research and development are often important in order to have sufficient funds to support a variety of R&D activities. The United States spends more on R&D than France, West Germany, and Japan combined.[17] For example, in 1978, national expenditures for research and development in the United States totaled $48.0 billion, compared to about $9.0 billion in France, $16.7 billion in West Germany, and $20.6 billion in Japan. National expenditures on R&D in the United Kingdom in 1978 (latest year available) came to approximately $7.0 billion. However, these differences in absolute levels of R&D funds are not as great as they have been in the past[18] and are not

[12]Ibid., p. 16.

[13]*U.S. Scientists and Engineers 1978*, National Science Foundation (NSF 80-304), p. 24; Ailes and Rushing, Training and Utilization of Scientists and Engineers: U.S. and U.S.S.R., p. 74-93. There is no strict comparability between advanced degrees of the two countries. The Candidate of Science degree appears to be a higher level of qualification than the U.S. master's degree but slightly less than the U.S. doctoral degree.

[14]*Engineering Our Future: Report of the Committee of Inquiry into the Engineering Profession*, pp. 203-214.

[15]*Science and Engineering Education for the 1980's and Beyond*, pp. 58-59.

[16]Based on data in *U.S. Scientists and Engineers 1978*, p. 36; *Employment and Earnings*, Bureau of Labor Statistics, March 1978, p. 46.

[17]Calculated using the R&D data in appendix table 1-3 and exchange rates found in *International Economic Indicators*, U.S. Department of Commerce, June 1980, p. 56.

[18]In 1967, for example, U.S. expenditures for research and development were $23.1 billion compared to $9.1 billion for the combined total of these four countries' R&D expenditures; whereas in 1978, their combined total ($53.4 billion) was greater than that of the United States ($48.0 billion).

quite as large when the size of the total economy is taken into consideration.

The ratio of national expenditures for research and development to the gross national product (R&D/GNP) has become a traditional relative indicator of national R&D activity because it reflects the proportion of a nation's resources devoted to R&D. This indicator is a convenient way to compare each country's R&D investments because it accounts for the size of a nation's economy.[19] At the same time it automatically compensates for fluctuating rates of inflation.[20] Figure 1-3 shows that the U.S. ratio of R&D to GNP peaked in 1964 at 2.96 and generally declined throughout the 1970's. France and the United Kingdom soon followed suit. The declines in all three countries occurred because R&D expenditures, while increasing, did not keep pace with the more rapid growth rate of the GNP. The U.S. ratio began rising again in 1979 and is expected to reach 2.37 in 1981.[21]

Through the mid-1970's, Japan and West Germany continued to increase R&D spending faster than their economies were growing—even though these two countries have experienced rapid real growth.[22] Japan's ratio now seems to have reached a plateau at around 1.93. The West German R&D-to-GNP ratio surpassed that of the United States in 1975 and reached a level of 2.36 in 1979.

It is important to note again that there is no known optimal national level of R&D investment. It has been argued that firms efficiently using R&D expenditures would generate very high sales volumes and thus would have a relatively low ratio of R&D to sales. Similarly, it is argued, nations effectively using R&D might have a low R&D-to-GNP ratio.[23] The early and mid-1960's were a unique period in U.S. history characterized by an enormous increase in Federal R&D spending to meet the "Sputnik challenge," and it is possible that the lower R&D-to-GNP ratios of the 1970's may be a return to "historically normal levels" of R&D spending.[24] For example, the U.S. ratio in 1958 was 2.38.[25]

R&D investments and economic growth seem to be mutually dependent. Past R&D investments have contributed greatly to GNP growth,[26] while at the same time, healthy economies tend to encourage R&D expenditures. Adequate growth accounting methods and causal models that directly link all contributions of R&D with rates of economic growth are not available. The economic effects of R&D are cumulative, occur through a complex set of interactions over long periods of time, and are difficult to trace.[27] Another problem in clearly defining the link between R&D and economic growth occurs because countries are not limited to the use of domestically produced R&D but can utilize foreign technology. Japan is an example of a country which has successfully built upon other nations' R&D activities. The precise causes underlying the relationship between R&D investments and economic growth are difficult to determine.

Civilian R&D

There are some major differences in the purposes and sponsors of research and development supported by individual countries. A gross differentia-

[19] How the resulting ratio should be interpreted is debatable. Denison, for instance, argues that, "Just because the size of the economy is, say, twice as big does it take twice as much R&D to obtain the same annual productivity gain?. . . An invention that cuts 1 percent from the production cost of 5 million automobiles should do as much for 10 million." "Explanations of Declining Productivity Growth," *Survey of Current Business*, Part II, August 1979, p. 6.

[20] This adjustment for inflation may only be partial as there is some preliminary evidence that industrial R&D may be more affected by inflation than is the GNP. See Edwin Mansfield, "R&D, Productivity, and Inflation," a paper presented at the fifth annual A.A.A.S. Colloquium on R&D policy, Washington, D.C., June 19, 1980. These comparisons would be more precise if adequate national R&D deflators were available, but they are only at the experimental stage.

[21] See the Chapter on Resources for Research and Development for further analysis of U.S. trends in funding sources and performers of R&D.

[22] For analyses of real GNP growth in these countries, see *International Economic Report of the President*, Council on International Economic Policy, Executive Office of the President, 1977, pp. 3-9; *Economic Report of the President*, Council of Economic Advisors, 1980, pp. 159-166.

[23] Raymond Vernon, "On Science Indicators, 1978," in *Papers Commissioned as Background for Science Indicators—1980*, vol I: Indicators of International Technology and Trade Flows, National Science Foundation, 1981.

[24] Nathan Rosenberg, "An Examination of International Technology Flows in Science Indicators 1978," in *Papers Commissioned as Background for Science Indicators—1980*, vol. I: Indicators of International Technology and Trade Flows, National Science Foundation, 1981.

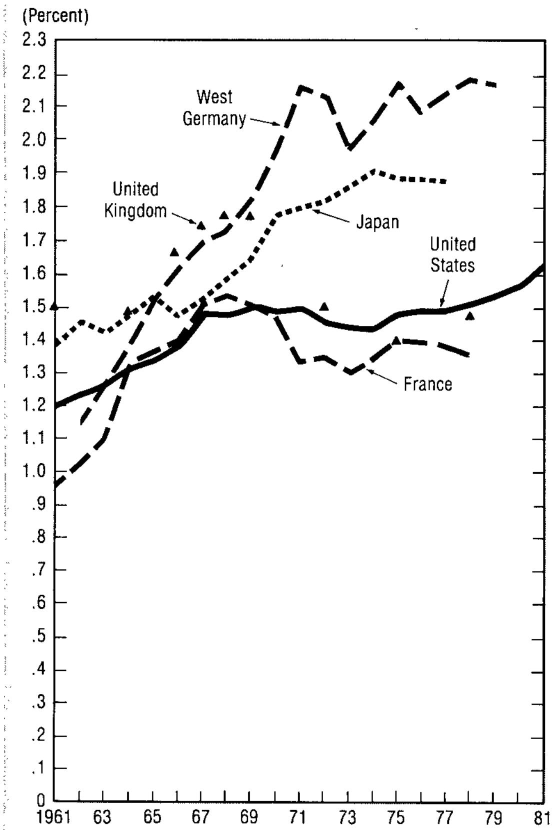
[25] National Science Foundation, unpublished data.

[26] See the sections on productivity of this chapter and the Industrial R&D and Technological Performance chapter for a discussion of studies relating R&D to increased economic growth and productivity. Also see "Productivity and Technical Innovations," Hearing before the Task Force on Inflation of the Committee on the Budget, U.S. House of Representatives, 96th Congress, July 23, 1979.

[27] Because of these difficulties, some feel that it may be necessary to readjust our expectations of the type of research possible in attempts to measure directly the economic impacts of R&D or a certain technological innovation. See Bela Gold, *Productivity, Technology and Capital* (Toronto: Lexington Books, 1979), pp. 6-8.

Figure 1-4

Estimated ratio of civilian[1] R&D expenditures to gross national products (GNP) for selected countries



[1]National expenditures excluding Government funds for defense and space R&D.

REFERENCE: Appendix table 1-4. Science Indicators — 1980

tion which can be examined is between defense and space R&D and civilian R&D. Although defense and space R&D does have important economic impacts,[28] it is primarily aimed at attaining other public goals. On the other hand, because civilian R&D is directly oriented toward economic and social needs or the expansion of general knowledge, it probably has a greater impact on economic growth and increased productivity.[29] National civilian R&D expenditures (privately funded as well as federally funded) are presented in figure 1-4 as a fraction of GNP. The figure shows that West Germany and Japan have had the highest ratios over the past two decades and have generally maintained civilian R&D growth patterns at a faster rate than their national economies were growing. The high civilian R&D ratios in Japan and West Germany are not surprising, given post-World War II restrictions that limited defense R&D expenditures in these two countries. A large percentage of Government R&D funds in these two countries is devoted to energy production and areas of economic development, including manufacturing, mining, telecommunications, agriculture, forestry, and fishing (see appendix table 1-5). These trends in civilian R&D in Japan and West Germany seem to parallel their productivity growth rates and R&D-intensive trade performance.[30]

The lower ratio of civilian R&D to GNP in the United States is related to the large percentage of Government R&D funds devoted to defense and space programs. This concentration is associated with major international defense obligations carried by the United States that require large R&D expenditures to ensure future capabilities.

Throughout the 1960's, the U.S. ratio of civilian R&D to GNP increased to a level of 1.5 percent. This growth is noteworthy because it occurred at a time when the total R&D per GNP ratio was declining. To some extent, this increase became possible because of cuts in Federal support for defense R&D and the completion of the Apollo Manned Space Program. After a temporary decline in the early 1970's, this ratio surpassed its former level and is expected to reach 1.66 percent in 1981. Even though the U.S. civilian R&D ratio is lower than that of Japan and West Germany, in absolute terms the U.S. level of investment in civilian R&D in 1977 was more than that of those two countries

[28]See, for example, James M. Utterback and Gilbert E. Murray, *The Influence of Defense Procurement and Sponsorship of Research and Development on the Development of the Civilian Electronics Industries*, CPA 77-5 (Cambridge, Mass.: Center for Policy Alternatives, Massachusetts Institute of Technology, 1977); *The Economic Value of Remote Sensing by Satellite: An ERTS Overview and the Value of Continuity of Service*, prepared for the National Aeronautics and Space Administration, 13 vols. (Princeton, N.J.: ECON, Inc., 1974). The difference between what is classified as defense and civilian R&D is somewhat arbitrary. Defense and space R&D often have industrial applications while civilian R&D can also be useful to space and defense goals. However, for general purposes, the distinction between civilian and defense, based on intended funding purposes, is useful.

[29]For instance, see Harvey Brooks, "What's Happening to the U.S. Lead in Technology?" *Harvard Business Review*, vol. 50 (May-June 1972), pp. 110-118; Robert Gilpin, *Technology, Economic Growth and International Competitiveness*, Joint Economic Committee of Congress, 1975.

[30]See the sections on trade and productivity in this chapter and Robert M. Dunn, Jr., *Economic Growth Among Industrialized Countries: Why the United States Lags* (Washington, D.C.: National Planning Association 1980), pp. 44-50.

combined.[31] U.S. civilian R&D expenditures have been influenced by Government expenditures in health and energy. In the United States, health R&D is viewed by the general public as a high priority[32] and receives a larger percentage of the national budget than in any other OECD country. About three-fourths of the total OECD health R&D expenditures are from the United States.

The United States is also one of the few OECD countries which have significantly and consistently increased public financing of energy research and development since the energy crisis began in 1973.[33] The U.S. energy R&D budget rose 469 percent from $0.6 billion in 1973, to $3.6 billion in 1980.[34] However, it should be noted that the energy portion of the U.S. budget for R&D was lower initially than that of many European countries, consequently the U.S. energy share of the R&D budget is not much greater than that of many other OECD countries and is less than the proportion the West German Government allots to energy R&D. The relatively greater increase in U.S. funding of energy R&D over this period may have been appropriate, since the United States consumes a large portion of the world's energy. In 1977, the United States represented 41 percent of the free world's energy consumption compared to 29 percent for Western Europe and 8 percent for Japan.[35]

As can be seen in table 1-1, a very large portion of the energy R&D funds has been allocated to nuclear energy in each of these countries, with the U.S. percentage being the lowest. However, since 1975, the share of nuclear energy R&D has declined in every case. There has been a cutback on nuclear fuels R&D in the European countries, even though fission and fusion R&D has been maintained.[36] In Japan, the proportion of nuclear energy R&D has declined in favor of energy conservation research.[37]

Government/Industry Funding Patterns

Differences in R&D funding patterns in various countries may be one of the factors affecting the contribution of research and development to economic growth. There is some evidence that privately financed R&D expenditures make a greater direct contribution to productivity growth than do publicly financed R&D expenditures.[38] This is due in part to differences in the objectives and purposes of the activities of the two sectors. Government R&D expenditures are often aimed at areas unlikely to receive support from the private sector, such as those that have high risk, high social benefit, or high costs. R&D efforts in this category include national defense or space programs, large energy projects, or unique facilities such as the VLA (Very Large Array) radio telescope or the Fermi Laboratory High Energy Accelerator. These Government-supported activities usually have long-range social and economic impact, in comparison to industrially funded research and development, which often has a greater impact on the economy in the short run because it is generally aimed at projects more likely to materialize into commercial use.[39] The question of the Government's

[31] In 1977, U.S. civilian R&D expenditures were $29.2 billion compared to the equivalent of $15.0 billion for Japan and $12.2 billion for West Germany. However, it should be remembered that these figures also reflect exchange rate differences, which fluctuate with the relative strengths of the currencies.

[32] The Public Attitudes Toward Science and Technology chapter shows that the U.S. public ranks the improvement of health care first on a list of areas that should receive Goverment science and technology funding.

[33] See appendix table 1-5 and *Analysis of the Research and Development Potentials of the Member States of the European Community*, Directorate-General for Research, Science, and Education (CREST) European Communities, 1979, pp. 60-65.

[34] National Science Foundation, special tabulation, unpublished. See the chapter on Resources for R&D and appendix table 2-16.

Table 1-1. Nuclear R&D as a percent of Government funding for energy R&D by countries

Countries	1975	1976	1977	1978
France	91	87	86	82
West Germany	89	88	84	74
United Kingdom	94	92	88	84
Japan	95	82	74	66
United States	44	44	43	40

[1]Based on Federal budget system which classifies some large programs which could be considered energy-related, such as inertial confinement fusion and high energy physics, under the defense and general science categories. The addition of these programs would only raise the nuclear proportion of the Federal energy budget by less than 6 percent.

NA = Not available.

SOURCES: O.E.C.D. special tabulations; *Japanese White Paper on Source and Technology; Analysis of the Research and Development Potentials of the Member States of the European Community*, CREST, European Communities, 1979, pp. 63-66; National Science Foundation, *An Analysis of R&D Funding by Function FY 1969-79, and Federal R&D Funding by Budget Functions FY 1979-81*; Yoshinobu Tsutsumi, "A Course for Japan as a Technological Power in the 1980's," *Shigen to Energi*, vol. 4 (February 1981), pp. 36-41.

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[35] *Annual Report to the Congress*, Energy Information Administration, Department of Education, 1979, p. x.

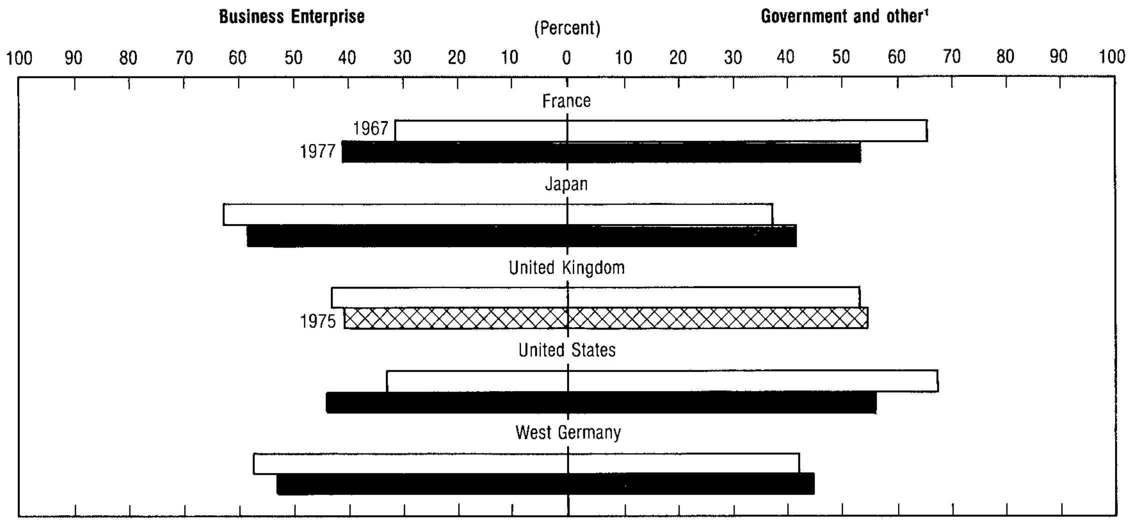
[36] *Analysis of the Research and Development Potentials of the Member States of the European Community*, p. 60-65.

[37] *1977 White Paper on Science and Technology*, Japanese Science and Technology Agency, Japan, December 1978, pp. 30-31; *1978 White Paper on Science and Technology*, Japanese Science and Technology Agency, Japan, October 1979, pp. 22-23.

[38] M. Ishaq Nadiri, "The Contribution of Research and Development to Economic Growth," *Relationships Between R&D and Economic Growth/Productivity*, National Science Foundation, 1977, pp. B5-B20.

[39] See testimonies of Edwin Mansfield and Nestor E. Terleckyj at Hearings before the Subcommittee on Domestic and International Scientific Planning and Analysis of the Committee on Science and Technology on *Federal Research and Development and the National Economy*, U.S. House of Representatives, 94th Congress, April 28, 1976, pp. 39-65, 149-197.

Figure 1-5
Percent distribution of gross expenditures on research and development by source of funds



[1] "Government and other" includes expenditures by Government, private nonprofit organizations, and the higher education sector.
NOTE: R&D funds from abroad are not shown in this figure but appear in Appendix table 1-7.
REFERENCE: Appendix table 1-7.

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proper role in supporting R&D can be illuminated by assessing the experience of other nations. As figure 1-5 demonstrates, there are wide differences between countries in the proportions of public and private R&D funding. In the United States, France, and the United Kingdom, public funds have historically been the most important source of national R&D expenditures, although the Government's role has recently declined in both the United States and France.[40] In Japan and West Germany, the majority of R&D funds is provided by industry. Both of these countries have had high growth rates of R&D expenditures and GNP. The industrial portion of R&D funds has declined somewhat in these two countries over the past decade, a trend which may be one of the factors underlying their recent slowdown in economic growth.[41]

The Japanese Government expects to play a larger role in funding R&D in the future because it believes that there has been a recent improvement in the technical levels of Japanese enterprises, a decrease in technical innovation in Europe and America, and an increasing reluctance by industrialized nations to export technology to Japan.[42] Although the Japanese Government has recently augmented its R&D funding assistance, it still directly funds a very small portion of industrial R&D; the Japanese industrial sector supplies 98 percent of the expenditures for industrial research and development. (See appendix table 1-8.) West Germany follows the same basic pattern, with industry supporting 80 percent of all industrial R&D. In contrast, Government provides between 25 and 35 percent of the funding for industrial R&D performed in the United States, the United Kingdom, and France. In these last two countries, funds from abroad represent about 6 and 8 percent of total industrial R&D expenditures.

As U.S. Government commitments to defense and relatively "uncontrollable portions" of the budget increase, the question has been raised as to whether U.S. industry will have to accept greater responsibility for supporting applied and technological R&D. In the United States, the Government's proportion of industrial R&D has decreased substantially over the past decade, from 53 percent

[40] Government still provides over half of all R&D funds in the United States and about 40 percent of all R&D expenditures in France.

[41] For a discussion of the slowdown in economic growth in these countries, see *Economic Report of the President*, Council of Economic Advisors, 1979, pp. 139-143.

[42] *1977 White Paper on Science and Technology*, p. 21.

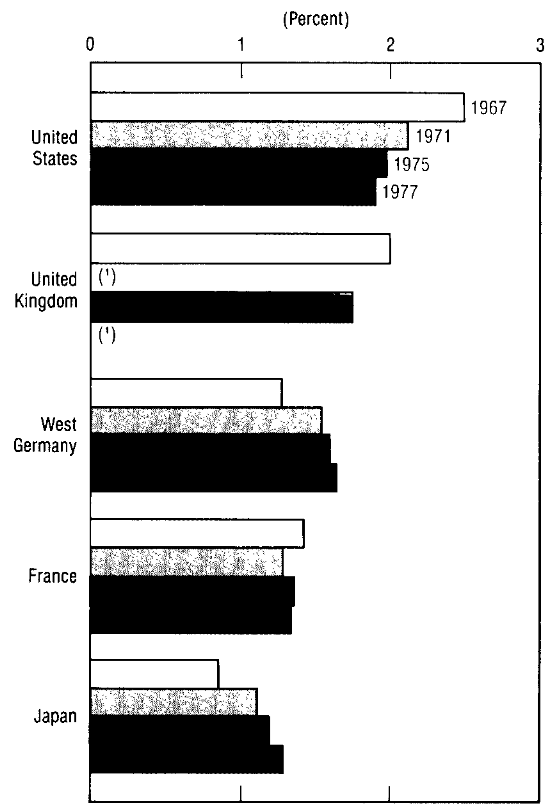
in 1967 to 35 percent in 1977. This decrease occurred principally in the aerospace and electrical and electronic industries.[43] Despite this decrease, U.S. Government funding of industrial R&D far surpasses that of other OECD governments, both in absolute dollar levels and in the portion of industrial R&D expenditures.

The Government R&D funding patterns discussed above seem to affect the industrial R&D intensity ratios of nations. R&D intensity is a concept which reflects the relative importance of R&D as an input factor to the overall industrial output. R&D intensity can be measured by the ratio of total industrial expenditures for research and development to the domestic industrial product.[44] Figure 1-6 shows that U.S. industry is more R&D-intensive than industries of the other countries examined, although its R&D intensity ratio has decreased as the U.S. Government's funding for industrial R&D has declined. Over the past decade, industrial R&D intensity has declined in the United States, the United Kingdom, and France, while increasing significantly in West Germany and Japan.

Of course, governments affect industrial R&D in many ways other than through direct financial support. They can encourage or inhibit investments in R&D and innovative activity indirectly through measures such as tax incentives, protective tariffs, monetary and fiscal policies affecting the availability of investment capital, environmental, health, and safety regulations, procurement practices, patent policies, etc. General economic policies aimed at combating inflation in the general economy or stagnation or unemployment in a certain industry can have an important effect on the amount and type of R&D conducted. There is evidence that these types of policy measures may have equal or greater impact on R&D and innovation than direct Government financial involvement.[45]

Although direct Government funding of industrial R&D in Japan is relatively small, extensive cooperation between Government, industry, and the banking establishment rebuilt the Japanese economy after World War II. Using and developing advanced technologies, Japanese industry has become a world leader in such fields as electronics, optics, and automobiles.[46] In West Germany, there is also a high level of cooperation between industry, universities, and Government to reduce the costs of R&D to private firms and to encourage innovation in advanced priority areas. For instance, under a "first innovations" program, the Government meets 50 percent of the commercial development costs of a promising new technology by providing an interest-free forgivable loan which is

Figure 1-6
Industrial R&D expenditures as a percent of the domestic product of industry for selected countries



¹U.K. data for 1971 and 1977 are not available.
REFERENCE: Appendix table 1-9.
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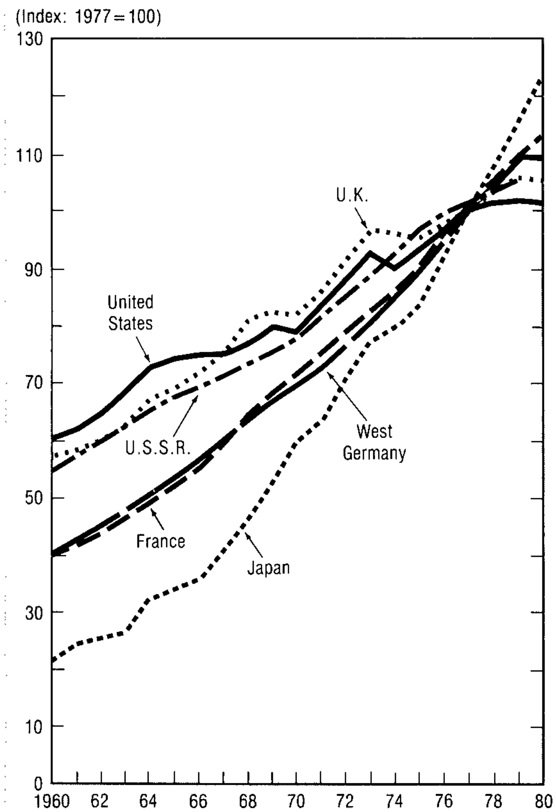
[43] See the chapters on Resources for Research and Development and Industrial R&D and Technological Progress.

[44] R&D as a percentage of sales or as a percentage of value added are also often used as measures of R&D intensity. Domestic product of industry (DPI) is the sum of the value added of resident producers in industry and is used as an indicator of the total resources available to industry.

[45] *National Support for Science and Technology: An Examination of Foreign Experience* (Cambridge, Mass.: Center for Policy Alternatives, Massachusetts Institute of Technology, 1976); A. Rubenstein et al., "Management Perceptions of Government Incentives to Technological Innovation in England, France, West Germany and Japan," *Research Policy*, vol. 6 (1977); T. Allen et al., "Government Influence on the Process of Innovation in Europe and Japan," *Research Policy*, vol. 7 (1978).

[46] Terutomo Ozawa, *Japan's Technological Challenge to the West, 1950-1970: Motivation and Accomplishment* (Cambridge, Mass.: Massachusetts Institute of Technology Press, 1974).

Figure 1-7
Relative change in productivity[1] in manufacturing industries for selected countries



[1]Output per worker hour.
NOTE: Estimates are shown for latest year.
REFERENCE: Appendix table 1-10.

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canceled if the effort fails.[47] The effect of various U.S. Government policies was recently examined in an extensive review of industrial innovation, followed by a variety of recommendations and programs to encourage private innovation and investment and the revitalization of American industry.[48]

R&D AND PRODUCTIVITY

Research and development is considered an important factor in economic development and productivity growth, although economists disagree about the precise extent of its contribution.[49] Improvements in productivity, on the other hand, often aid the conduct of research and development, as high productivity helps to increase profits and fight inflation.[50]

Productivity is commonly expressed as output per worker-hour, but this measure does not reflect the labor input alone; it also includes the contributions of technological advancement, capital investment, level of output, capacity utilization, energy use, and managerial skills.[51] Figure 1-7 presents trends in the relative change in output per worker-hour in individual countries. Comparisons of actual productivity levels in different countries are available in appendix table 1-11.

Over the past decade, the United States has experienced slower growth in manufacturing productivity than have most industrialized countries. From 1970 to 1980, productivity in manufacturing industries grew almost four times faster in Japan (102 percent) and twice as fast in France (61 percent) and West Germany (60 percent) as in the United States (28 percent). Productivity gains in the Soviet Union have also been greater than those in the United States.[52]

However, the United States still has the highest productivity levels among these countries. Comparing 1980 gross domestic product per employed

[47]J. Herbert Hollomon, "Government and the Innovation Process," *Technology Review*, vol. 81 (May 1979), pp. 37-38.

[48]*Advisory Committee on Industrial Innovation: Final Report*, U.S. Department of Commerce, 1979; "Reindustrialization—A Foreign Word to Hard-Pressed American Workers," *National Journal*, vol. 12 (October 25, 1980), pp. 1784-1789; *America's New Beginning: A Program for Economic Recovery*, The White House, February 18, 1981.

[49]For instance, John Kendrick calculates higher estimates of the contribution of organized R&D than does Zvi Griliches or Edward Denison. See John W. Kendrick, *The Formation and Stocks of Total Capital* (New York: National Bureau of Economic Research, 1976); "Total Investment and Productivity Developments," paper prepared for the Joint Session of the American Finance Association and the American Economic Association, New York, December 30, 1977; Zvi Griliches, "Research Expenditures and Growth Accounting," in B. R. Williams (ed.), *Science and Technology in Economic Growth* (New York: Halsted Press for the International Economic Association, 1973); Zvi Griliches, "Issues in Assessing the Contribution of Research and Development to Productivity Growth," *The Bell Journal of Economics*, vol. 10 (Spring 1979); Edward E. Denison, *Accounting for Slower Economic Growth: The United States in the 1970's*, (Washington, D.C.: Brookings Institution, 1980), pp. 122-147.

[50]*NSF Colloquium on the Relationships between R&D and Economic Growth/Productivity*, National Science Foundation, November 9, 1977.

[51]Patricia Capdevielle and Charles Wallace, *International Comparisons of Manufacturing Productivity and Labor Costs: Preliminary Measures for 1980*, Bureau of Labor Statistics, U.S. Department of Labor, May 20, 1981, p. 2.

[52]U.S.S.R. figures for manufacturing productivity were provided by Francis Rushing of SRI International. Although the Soviet Union has made higher relative investments in R&D than Japan and West Germany, it has experienced smaller productivity gains. This is possibly due to the lack of incentives for the introduction of technical advances into production on a mass scale, or to a high proportion of R&D believed to be devoted to military/defense R&D.

Table 1-2. Real gross domestic product per employed person for selected countries compared with the United States

[Index, United States = 100]

Countries	1960	1965	1970	1975	1980 Prel.
United States	100.0	100.0	100.0	100.0	100.0
France	54.2	60.2	71.1	81.0	89.4
West Germany ...	56.6	60.1	71.3	78.6	88.7
Japan	24.1	31.3	48.7	57.2	68.4
United Kingdom ..	54.5	52.5	57.6	57.1	60.5
Canada	90.4	89.4	92.6	94.9	92.1

[1]Output based on international price weights to enable comparable cross-country comparisons.

REFERENCE: Appendix table 1-11.

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person, the productivity level in France and West Germany was over 10 percent lower than that in the United States, and the productivity level in Japan was over 30 percent below the U.S. level. Nevertheless, the U.S. lead in productivity has decreased over the past decade as table 1-2 shows.

Although there is currently a great deal of concern over reduced productivity growth in the United States, there have also been significant slowdowns in output growth in most industrialized countries since the worldwide recession of 1974-75. From 1973 to 1980, output growth in the United States was greater than that in the United Kingdom, but less than that in Japan, West Germany, and France. As output slowed, most countries reduced employment hours, thereby improving their productivity growth rates. The United States was the only one of these countries to generally maintain manufacturing employment and hours since 1973.[53]

The contribution of research and development to productivity and economic growth is difficult to quantify. There are numerous conceptual and empirical problems, such as insufficient understanding of how research is transformed into technological innovation and how it affects the economy. Other difficulties include isolating the positive and negative effects of specific factors on output growth and selecting criteria for measuring the influence of R&D.

Current productivity statistics and GNP-accounting procedures are also seriously limited. Increased environmental protection and improved human health and longevity, for example, are not adequately reflected in these measures. Measured productivity growth may significantly understate the increased value brought about by a technical advance that leads to improved quality or a broader range of goods and services.[54] For instance, GNP does not reflect the introduction of a new pharmaceutical with enhanced lifesaving capabilities which replaces a less effective drug, if it has the same production costs and sales. In addition, it is difficult to measure the output of services (such as medical services) although they constitute a growing proportion of our economies and are beneficiaries of the R&D effort.[55] Even with these measurement difficulties, it is generally agreed that investments in R&D and technological innovation, particularly civilian and industrial investments, have a positive effect on productivity and economic growth. Numerous studies have examined the impact of R&D at various levels—including specific innovations, firms, industries, and the whole economy. Together these studies give strong evidence that the contribution of R&D is important and indicate that the rate of return on R&D investment is as high or higher than other types of investments.[56] It is likely that the increases in R&D investments, particularly in civilian and industrial areas, by Japan and West Germany have contributed to their large productivity gains.

The sharp decline in U.S. productivity growth since 1973 has been a source of great national concern, but the causes have not yet been clearly diagnosed. One economist[57] carefully examined many of

[53]Capdevielle and Wallace, pp. 1-4 and Index Tables.

[54]A recent study which measured the impact of R&D on commercial air transportation circumvented some of these problems by comparing savings due to R&D expenditures with the cash flow returns from alternative investments and by comparing the costs of operating a "phantom fleet" of older-technology aircraft with the costs of operating the actual fleet. The gains in domestic airline productivity in only 1 year alone (1976) were found to be sufficient to pay nearly twice the costs of all the aeronautical R&D performed in the U.S. from 1923 to 1976. See Ralph C. Lenz, John A. Machnic, and Anthony W. Elkins, *The Influence of Aeronautical R&D Expenditures Upon the Productivity of Air Transportation* (Dayton: University of Dayton Research Institute, 1980), p. 29.

[55]*Science and Technology in the New Socio-Economic Context* (Paris: Committee for Scientific and Technological Policy, Organisation for Economic Co-operation and Development, September 11, 1979), pp. 92-95, 100-105.

[56]*Relationships between R&D and Economic Growth/Productivity;* Eleanor Thomas, "Recent Research on R&D and Productivity Growth: A Changing Relationship Between Input and Impact Indicators," a paper presented at the OECD Science and Technology Indicators Conference, Paris, September 15-19, 1980.

[57]Denison, pp. 122-147. Others have blamed modern management principles for the sluggish U.S. economic performance; See Robert H. Haynes and William J. Abernathy, "Managing Our Way To Economic Decline," *Harvard Business Review*, vol. 58 (July/August, 1980), pp. 67-77.

the possible reasons for the productivity slowdown—including skyrocketing energy costs,[58] pressures of inflation, high interest rates, and Government regulation—and found that no single hypothesis, including curtailment of R&D expenditures, seems to provide a probable explanation of the sharp decline in productivity growth after 1973. He noted, however, that R&D has contributed to productivity growth in the past and is a promising way to promote future productivity growth. Other economists have stressed the importance of R&D and high rates of investment in plant and equipment in encouraging economic growth and have concluded that low investment rates have been a major source of the poor U.S. productivity performance.[59]

If R&D is to influence economic growth effectively, it must be utilized. New capital investments often embody new technologies and R&D advances, and so capital investment rates can be viewed as a rough and partial indicator of the application of new technology. Capital investment is an important ingredient in productivity growth; low rates of investment in new plant and equipment have been blamed as a major cause of the U.S. productivity slowdown and a roadblock to innovation.[60] Although total U.S. expenditure levels for plant and equipment are still higher than in other countries, as a percentage of output, new nonresidential capital investment rates have been proportionately smaller in the United States than in other major industrial countries in the 1960's and the 1970's. Table 1-3 shows that the proportion of capital investment to output—both of manufacturing and of the total economy—has been lower in the United States than in any of the other industrialized countries examined here. Relative to the size of output, West Germany had a capital investment rate almost twice that, and Japan three times that, of the United States.

One important reason for the higher rates of capital formation by other countries in the 1960's was that they were still trying to catch up with U.S. technology. The opportunity to obtain more sophisticated technology from the United States helped to ensure a high marginal rate of return to capital, which in turn encouraged high rates of capital investment.[61]

Replacement of capital equipment is an important factor affecting productivity growth; a 10-year age period is frequently used as a measure of machine utility. In Japan and West Germany, about two-thirds of the machine tools are under 10 years old, while the U.S. has one of the smallest fractions under 10 years old of any leading industrialized nation (33 percent in 1973). Japan has

[58] For a discussion of the effect on industrialized economies of the continuing energy crises, including sharp increases in oil prices in 1979, see *Economic Report of the President*, pp. 156-183.

[59] Dunn, pp. 12-17, 44-50; Dale Jorgenson and Mieko Nishimizu "U.S. and Japanese Economic Growth: An International Comparison," *Economic Journal*, vol. 88 (December 1978), pp. 707-726.

[60] Ibid.; *Stimulating Technological Progress* (New York: Committee for Economic Development, 1980), pp. 20-25.

[61] Rosenberg.

Table 1-3. Capital investment, excluding residential construction, as a percent of output for selected countries[1]

Item and years	United States	Canada	Japan	France	West Germany	United Kingdom
Total economy						
1960-69	14.9	20.0	28.7	19.4	20.1	16.5
1970-78	14.5	19.2	27.1	18.6	18.6	17.5
1960-78	14.7	19.6	28.0	19.0	19.4	17.0
Manufacturing						
1960-69	8.8	14.4	29.9	NA	16.3	13.4
1970-78[2]	9.7	15.1	26.5	NA	15.2	13.7
1960-78[2]	9.2	14.7	28.8	NA	15.9	13.5

NA = Not available.

[1] Fixed investment at market prices as a percent of output at factor cost, in current dollar prices.
[2] Period ending 1974 for Japan, 1976 for Germany, and 1977 for Canada.

SOURCE: U. S. Department of Labor, Bureau of Labor Statistics, Office of Productivity and Technology, June 1980.

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also been a leader in using numerically controlled machines and robot applications.[62]

Summary of R&D Investments and Productivity

The United States has a greater number of scientists and engineers engaged in R&D than most industrial countries and also has the highest concentration of R&D scientists and engineers in the labor force of any other country except the Soviet Union. In 1980, this ratio was about 6 S/E's involved in research and development for every 1,000 individuals in the labor force. The Soviet Union conferred 132 percent more S/E bachelor's degrees than the United States (416,900 compared to 179,700 in the United States) in 1979, including five times the number of engineers. There is reason to believe, however, that many of the Soviet students have received training which is of lower quality and much narrower in scope than that offered in the United States.

Although the United States spends more on R&D than France, West Germany, and Japan combined, the picture is somewhat different when the size of the economy is taken into consideration. In 1978, the U.S. ratio of total R&D to GNP (2.23) was higher (including defense R&D) than that of Japan (1.93) but lower than that of West Germany (2.37). The R&D to GNP ratio peaked in the United States in 1964 at 2.96 and steadily declined through the 1970's. It began rising again in 1979 and is expected to reach 2.37 in 1981. Japan and West Germany continued to increase R&D spending faster than their economies were growing through the mid-1970's—even though these two countries have experienced rapid real GNP growth.

In addition, over the past two decades Japan and West Germany have had the highest proportions of national civilian R&D expenditures to GNP. This concentration may have assisted the Japanese and West Germans to increase productivity rates. Even though the U.S. ratio of civilian R&D to GNP is higher than its level in the 1960's and rose to 1.7 in 1981, it is still below the ratios reached by West Germany and Japan in the late 1970's. However, in absolute terms the U.S. level of investment in civilian R&D is more than that of these two countries combined.

[62] Saul Kurlat and Robert Gonsalves, *The Impact of Robotics: A Technology Assessment*, National Science Foundation, 1979, pp. 182-223; *Background Readings on Science, Technology, and Energy R&D in Japan and China*, Committee on Science and Technology, U.S. House of Representatives, 97th Congress, January 1981, pp. 77-114.

OUTPUTS OF R&D

It is not now possible to quantify precisely the results of research, much less their importance or value. Nor is it feasible now to determine how R&D funding has advanced technological knowledge. However, trends in scientific literature and patents can be considered quantifiable outputs of R&D. This section presents indicators of scientific and technical literature and attempts to determine trends in the U.S. contribution to world science in terms of the number and relative influence of articles written by U.S. scientists and engineers. Although there are important limitations, patent data can be used as output indicators of technological invention. Foreign patenting activity reflects commercial interest in foreign markets.

Scientific Literature

The publication of scientific literature adds to the body of world scientific knowledge and may help to stimulate or catalyze other research. Scientific findings are generally published in scientific and technical journals and, thus, publication counts have long been accepted as output indicators of scientific activity.[63] Scientific literature indicators have several limitations for use in international comparisons of scientific activity. National publication characteristics may be affected by the number of national journals and the space available within each journal.[64] Since about three-fourths of the scientific literature examined here was published in journals of countries other than the authors' own,[65] these limitations have little effect on the scientific literature indicators.

The scientific literature indicators presented in this report are based on a set of over 2,100 highly cited or influential journals. This set of journals remained the same for the period examined (1973-1979) so that more valid longitudinal comparisons could be made. It does not, therefore, reflect the growth of publications caused by articles in journals which have appeared since 1973 or which are

[63] See, for example, Derek J. de Solla Price, *Little Science, Big Science* (New York: Columbia University Press, 1963); Francis Narin et al., *Evaluative Bibliometrics: The Use of Publication and Citation Analysis in the Evaluation of Scientific Activity* (Cherry Hill, N.J.: Computer Horizons, Inc., 1976).

[64] For a further discussion of the limitations of these data see Mark Carpenter, *International Science Indicators Development of Indicators of International Scientific Activity Using a Science Citation Index* (Cherry Hill, N.J.: Computer Horizons, Inc. 1979), NTIS PB-293-033.

[65] The author's country is determined by the location of the author's organization, and the journal's country is defined as the country where it is published.

Table 1-4. U.S. proportion of the world's articles[1]

Field[2]	Percent 1973	1975	1977	1978	1979
All fields	39	38	38	38	37
Clinical medicine	43	43	43	43	43
Biomedicine	39	39	39	39	40
Biology	46	45	42	42	43
Chemistry	23	22	22	21	21
Physics	33	32	30	31	30
Earth and space sciences	47	44	45	45	45
Engineering and technology	42	41	40	39	41
Mathematics	48	44	41	40	40

[1]Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.
[2]See Appendix table 1-13 for a description of the subfields included in these fields.

REFERENCE: appendix table 1-12. Science Indicators—1980

not considered "influential" as the term is used here. Even when an expanded set of journals is examined, the U.S. share remains about the same (36 percent compared to 37 percent for the fixed journal set). Critical review prior to the publication of articles appearing in these influential journals helps to ensure the quality and significance of this body of literature, even though there may be differences in the theoretical or practical importance of the individual articles.

Table 1-4 shows that the U.S. proportion of the world's scientific literature for all fields together has been stable at about 37 percent over the 1973 to 1979 period, indicating that U.S. scientists are internationally competitive in their research outputs. Individual field shares ranged from 21 percent for chemistry to 45 percent for earth and space sciences in 1979. Biomedicine was the only field in which the U.S. fraction of the world's literature increased (albeit slightly) since 1973. Growth in the number of biomedicine articles helped to maintain the overall U.S. proportion of world scientific literature despite declines in other fields. The category of biomedicine includes such fast-growing subfields as genetics, physiology, biomedical engineering, cell biology, biochemistry, and microbiology. (See appendix table 1-13 for a list of all the subfields associated with each of these fields.) U.S. mathematics literature dropped in its proportion from 48 percent in 1973 to 40 percent in 1979; however, the share has stabilized and no longer appears to be declining, in part because non-U.S. mathematics articles also have decreased.

The actual number of articles published by U.S. authors declined in every field except the two fields with the largest number of articles—clinical medicine (up 4 percent) and biomedicine (up 10 percent). Non-U.S. articles experienced little or no decreases in six of the eight fields (see appendix table 1-12). The largest U.S. declines over the 1973-79 period were in mathematics (31 percent) and engineering (25 percent). The decline in U.S. engineering articles occurred across almost all subfields; nuclear technology was the only engineering subfield which rose (63 percent). There were also similar decreases in non-U.S. engineering articles, so the U.S. share remained relatively stable.

U.S. authors are responsible for a large portion of the world's influential scientific and technical literature. Therefore, it is to be expected that U.S. literature would be widely used and highly cited throughout the world. Citations are used to measure influence and quality, under the assumption that the most significant literature will be more frequently cited than routine literature. A number of studies support this assumption, finding high correlations between the number of citations to an author's work and other measures of scientific importance, such as judgments of researchers in the field.[66] Although some articles may be cited only for the criticisms they evoke, and other articles may be infrequently cited because they are not readily available, these situations are not generally the case for articles appearing in the set of journals selected for this study.

Table 1-5 presents citation ratios[67] for U.S. articles, adjusted for the size of the literature; a ratio greater than 1.00 reflects more influence than could be expected from the size of a nation's body of literature. According to this measure, U.S. scientific literature is remarkably influential, being cited over 80 percent more than could be expected. Even when U.S. usage of its own literature is excluded from the analysis, in all fields except biology, foreign authors still cite U.S. scientific literature more than is accounted for by the American share of the world's literature. In terms of specific fields, U.S. literature in chemistry, physics, and the earth and space sciences is the most highly cited.

Non-U.S. citations to all fields of U.S. scientific literature decreased during the period 1973 to

[66]See Eugene Garfield, *Citation Indexing—Its Theory and Application in Science, Technology, and Humanities* (New York: Wiley, 1979); S. M. Lawani, "Citation Analysis and the Quality of Scientific Productivity," *Bioscience*, vol. 27 (January 1977), pp. 26-34; Steven Cole, "Scientific Reward Systems: A Comparative Analysis," in Robert Alun Jones (ed.), *Research in the Sociology of Knowledge, Science, and Art* (Greenwich, Conn.: Jai Press, 1978); Paul R. McAllister, Richard C. Anderson, and Francis Narin, "Comparison of Peer and Citation Assessment of the Influence of Scientific Journals," *Journal of the American Society for Information Science* (May 1980), pp. 147-152.

[67]These ratios are calculated by a new method that uses citations from subsequent years to describe the influence of a given year's literature; thus, they differ from apparently similar indices in previous *Science Indicators* reports.

Table 1-5. Relative citation ratios[1] for articles[2] by field

Field[3]	1973	1975	1977
World citations to U. S.:			
All fields	1.87	1.88	1.84
Clinical medicine	1.73	1.75	1.73
Biomedicine	1.88	1.85	1.76
Biology	1.33	1.37	1.39
Chemistry	2.38	2.42	2.47
Physics	2.19	2.21	2.29
Earth and space sciences	1.80	1.90	1.82
Engineering & technology	1.76	1.72	1.75
Mathematics	1.55	1.58	1.65
Non-U. S. citations to U. S.:			
All fields	1.30	1.25	1.16
Clinical medicine	1.23	1.20	1.13
Biomedicine	1.38	1.28	1.13
Biology	.79	.76	.72
Chemistry	1.60	1.53	1.48
Physics	1.62	1.55	1.54
Earth and space sciences	1.33	1.39	1.31
Engineering & technology	1.13	.99	.97
Mathematics	.99	.98	.96

[1]A citation ratio of 1.00 reflects no over- or under-citing of the U. S. scientific and technical literature, whereas a higher ratio indicates a greater influence, impact or utility than would have been expected from the number of U. S. articles for that year. For example, the U. S. biology literature for 1973 received 33 percent more citations from the world literature of later years than could be accounted for by the U. S. share of the world's biology articles published in 1973.

[2]Based on the articles, notes and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* corporate tapes of the Institute for Scientific Information. For the size of this data base, see Appendix table 1-12.

[3]See Appendix table 1-13 for a description of the subfields included in these fields. Note that because psychology journals began to be removed from the *SCI* in 1978 for inclusion in the *Social Sciences Citation Index*, the "All fields" totals for all years exclude psychology articles.

NOTE: These ratios are calculated by a new method that uses citations from subsequent years to describe the influence of a given year's literature; thus they differ from similar indexes used in previous *Science Indicators* reports.

REFERENCE: Appendix table 1-14. Science Indicators — 1980

1977, from 30 percent to 16 percent more than what could be accounted for by the U.S. proportion of the world's literature in those years. This decline in foreign usage occurred in every scientific field. Even so, during these 5 years, U.S. literature had the highest ratio of foreign-to-domestic citations of any country examined. This is also generally true in individual fields with the exception of engineering and biology, which frequently ranked second and third. U.S. self-citation ratios (an author citing publications by S/E's from his or her own country) are among the lowest in the field of biology and the highest in chemistry and physics, indicating that U.S. citation patterns are similar to those of the rest of the world.

Because authors are often more aware of domestic than foreign research findings, most countries have high self-citation ratios. The United States had the lowest self-citation ratios in each of the major fields of any country in each year from 1973 to 1977, indicating that U.S. scientists and engineers are well integrated into the world's scientific community and are using foreign research findings.

Foreign Patenting in the United States

Although there are limitations which should be recognized, patent data represent one of the best available output indicators of inventive activity.[68] The advantage of patents is that they are available for many different countries, in great detail, and over extended periods of time. Many studies support the value of patent statistics as output indicators.[69] Several recent reports have used patent data in analyses of industrial innovation, but because patents represent a stage in the innovation process prior to market introduction,[70] patent data more appropriately reflect inventive output. The propensity to patent in another country is also probably related to the perceived market potential of that country.[71]

Patent data have limitations as indicators of R&D output because many factors influence patent activity.[72] For instance, not all new ideas or inventions are patented, and those that are do not necessarily represent the same level of technical or economic value. Patent laws and practices are not uniform across countries and may be subject to change. However, foreign-origin patents in a given country must meet the same requirements of novelty

[68]See *The Meaning of Patent Statistics*, National Science Foundation, 1979. This report contains papers by four experts on the legal and economic aspects of patenting: Dr. James L. Harris, Prof. Mary A. Holman, Prof. Edmund W. Kitch, and Prof. Keith Pavitt.

[69]Jacob Schmookler and Zvi Griliches, "Inventing and Maximizing," *American Economic Review*, vol. 53 (September 1963), pp. 725-729. Also see Jacob Schmookler, *Invention and Economic Growth* (Cambridge, Mass.: Harvard University Press, 1966), p. 184; Frederic M. Scherer, "Corporate Inventive Output: Profits and Growth," *Journal of Political Economy*, vol. 73 (June 1975), pp. 290-297; William S. Comanor and Frederic M. Scherer, "Patent Statistics as a Measure of Technological Change," *Journal of Political Economy*, vol. 77, (May/June 1969), pp. 392-398; Frederic M. Scherer, "Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions," *American Economic Review*, vol. 55 (December 1965), pp. 1097-1125; Edwin Mansfield, *The Economics of Technological Change* (New York: Norton, 1968), p. 36.

[70]Mary Ellen Mogee, *Technology and Trade: Some Indicators of the State of U.S. Industrial Innovation*, Committee on Ways and Means, U.S. House of Representatives, April 21, 1980; Kerry Schott, *Innovation in the United Kingdom, Canada, and the United States* (Eastbourne, England: British North American Committee, sponsored in the United States by the National Planning Association, 1981). These reports acknowledge this point but present patent data due to the paucity of innovation indicators.

[71]Dennis Schiffel and Carole Kitti, "Rates of Invention: International Patent Comparisons," *Research Policy*, vol. 7 (October 1978), pp. 324-340.

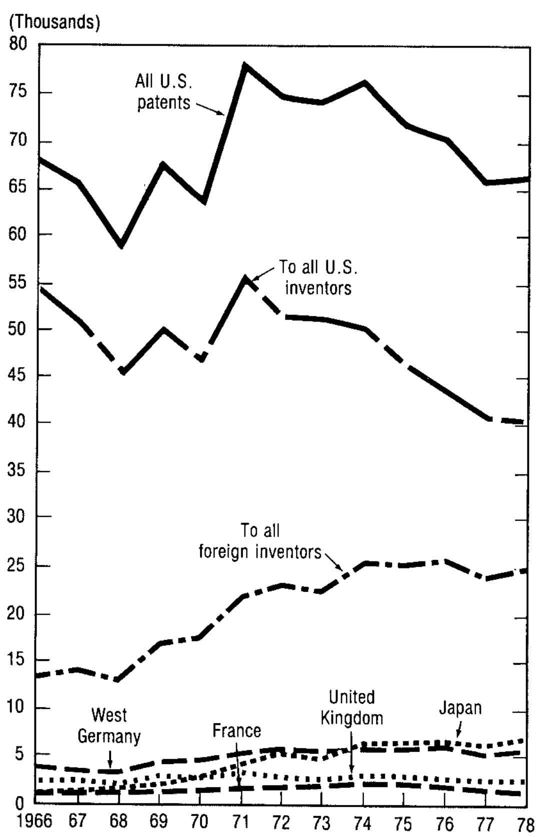
[72]See the Industrial R&D and Technical Progress chapter of this report and *Science Indicators—1978* for a complete discussion of the various factors which affect patenting activity.

as domestic-origin patents, and therefore represent approximately the same degree of originality in that country. The indicators presented here generally are focused on foreign patenting activities within a given country.

U.S. domestic patent trends show a 16-percent decline in patenting by U.S. inventors from 1971 to 1978, principally due to decreased patenting by persons employed by U.S. corporations.[73] In contrast, foreign patenting in the United States rose 11 percent over the same period (see figure 1-8).

[73] See the patent section of the Industrial R&D and Technological Progress chapter. Patent counts for 1979 are unreliable because the Patent and Trademark Office did not have enough money in that year to print all approved patents; thus, they are not used in the analysis but are shown in appendix table 1-15.

Figure 1-8
U.S. patents granted to inventors from selected countries by date of grant and nationality of inventor



REFERENCE: Appendix table 1-15.

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Much of this increase was due to Japanese-origin patents; from 1971 to 1978 the number of U.S. patents granted to Japanese inventors rose 71 percent. Patenting activity by West German inventors grew only 6 percent and patents granted to inventors from the United Kingdom, Canada, and France remained steady or declined (see appendix table 1-15). More than half of all the foreign-origin patents granted by the United States in 1978 were assigned to inventors from Japan and West Germany (28 percent and 24 percent, respectively).

There are several possible causes for the decline in U.S. domestic patenting activity. Lower profit margins and large capital investments in existing products and processes may tend to discourage interest in change and innovation. Some industries may be trying to hold down costs by screening patentable ideas more carefully. If so, the quality and economic promise of the patents is probably increasing, but this is a difficult premise to examine. It is also possible that an increased emphasis by U.S. industry on short-term payoff and cost-cutting research rather than long-term research has led to more process rather than product innovations.[74] Since it is generally believed that process inventions are less likely to be patented than new products, it is possible that this change in research emphasis has led to increased usage of trade secrets and decreased patenting activity in some industries. There are differences among companies and among industries in the use of patents versus the use of trade secrets to protect industrial property. The propensity to patent is highest in industries such as the drug industry in which technical advances can be copied by competitors with a minimum of independent development work. The propensity to patent is lowest in industries in which technical advances are not easily copied and where technological change occurs very rapidly. Since these factors operate to different degrees in various industries, patenting trends could be expected to vary among industries and product fields. Because patenting activity by U.S. corporations has decreased in almost all product fields,[75] it is likely that the decrease is not primarily attributable to any of the above-mentioned factors but may well indicate a

[74] See the section on basic research in industry of the Industrial R&D and Technological Progress chapter and Howard K. Nason, Joseph A. Steger, and George E. Manners, *Support of Basic Research by Industry* (St. Louis, Mo.: Industrial Research Institute Research Corporation, 1978), p. 43.

[75] Declines occurred in 87 percent of the product fields. The exceptions are aircraft engines and turbines, drugs, soap, agricultural chemicals, and possibly petroleum and plastics.

decrease in the rate of production of inventions across U.S. industry.[76]

Foreign patenting activity may be affected by many of the same factors. Appendix table 1-16 presents data on patents granted in selected countries. It shows that from 1971 to 1977 domestic patenting declined in the United Kingdom, Canada, and France. At the same time, Japan and West Germany showed substantial increases in their domestic patenting activity. The number of patents granted to nationals increased 74 percent in Japan and 30 percent in West Germany. Foreign patenting activity in the United States has been related both to increased foreign inventive activity and to interest in the U.S. market. Studies have shown that foreign patenting activity in the United States by selected OECD countries correlates significantly with industrial R&D in these countries. This correlation is especially high for the manufacturing sector as a whole and for the chemical, electrical and electronic, and nonelectrical machinery industries. Over half of all industrial R&D occurs in these three industries.[77] High correlations also have been found between patent activity in the United States and export shares of 10 OECD countries, suggesting that invention is an important element in international competitiveness, particularly in chemicals, capital goods, and durable consumer goods.[78]

Foreign patenting in the United States also may have been influenced by certain attractive characteristics of the U.S. patent and market system. U.S. patents provide protection for the introduction of a new technology or product to the large homogeneous U.S. market, whereas patents granted in another country may represent protection in a smaller market area. In addition, a U.S. patent does not have "working" requirements while those granted by most other countries do, and there have been no maintenance fees charged after issuance of a U.S. patent, while yearly taxes must be paid in many other countries. (A 1980 patent law instituted maintenance fees for U.S. patents.)

Foreign patenting activity in the United States spreads across a wide variety of products. Table 1-6 shows that in 1977-79 almost half of the U.S.

Table 1-6. Percentage of total U.S. patents granted to foreign inventors by product field: 1977-1979

Product fields	Foreign	U.S.-owned foreign[1]
Drugs and medicines	49	15
Primary metals	48	5
Aircraft and parts	46	3
Textile mill products	44	9
Chemicals, excluding drugs and medicines	42	13
Nonelectrical machinery	41	5
Motor vehicles and other transportation	39	3
Food and kindred products	39	9
Professional and scientific instruments	38	6
Communication equipment and electronic components	38	14
Stone, clay, glass and concrete products	36	7
Rubber and miscellaneous plastic products	35	6
Electrical equipment, except communication equipment	35	10
Fabricated metal products	31	7
Petroleum and natural gas extraction and petroleum refining	19	16

[1]Patents with a foreign resident inventor that are assigned to a U.S. organization divided by the total number of U.S. patents with a foreign resident inventor.

SOURCE: Compiled from information in Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, *Indicators of the Patent Output of U.S. Industry, IV (1963-1979)*, June 1980.

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patents in the fields of drugs and medicines and primary metals were granted to foreign inventors; foreign patents account for between 30 and 40 percent of most of the other fields. However, many of these foreign patents are actually assigned or owned by U.S. companies or individuals. For instance, although 42 percent of all U.S. chemical patents are granted to foreign inventors, 13 percent of these foreign-origin patents are owned by U.S. entities. The fields which have relatively high percentages of U.S.-owned foreign patents are the areas corresponding to high levels of U.S.-direct investment and research activity abroad.[79] It is possible that U.S. laboratories abroad supported the R&D that resulted in the patented inventions.

Appendix table 1-17 presents by product field, the number of U.S. patents granted to inventors from 15 individual countries. Foreign participation in U.S. patenting activity seems to be highly concentrated in only a few countries. In each major product field, over half of the foreign activity from 1963-1979 can be attributed to only three countries; all but one product field is dominated by West Germany, Japan, and the United Kingdom. For the field of petroleum and natural gas extraction and refining, the United Kingdom, West Ger-

[76]U.S. patenting activity and the factors affecting these trends are more fully discussed in the Industrial R&D and Technological Progress chapter.

[77]Keith Pavitt, "Using Patent Statistics in 'Science Indicators:' Possibilities and Problems," *The Meaning of Patent Statistics*, National Science Foundation, 1979.

[78]Keith Pavitt and Luc Soete, "Innovative Activities and Export Shares: Some Comparisons between Industries and Countries," in Keith Pavitt (ed.), *Technical Innovation and British Economic Performance* (London: Macmillan, 1980).

[79]See appendix table 1-22 and text table 1-9.

many, and Canada are the main foreign country participants. Almost half (48 percent) of all foreign-origin U.S. patents are in two product groups—nonelectrical machinery and chemicals except drugs and medicines. This parallels U.S. domestic patenting activity, since 46 percent of all U.S. domestic patents are also granted in these two product fields.

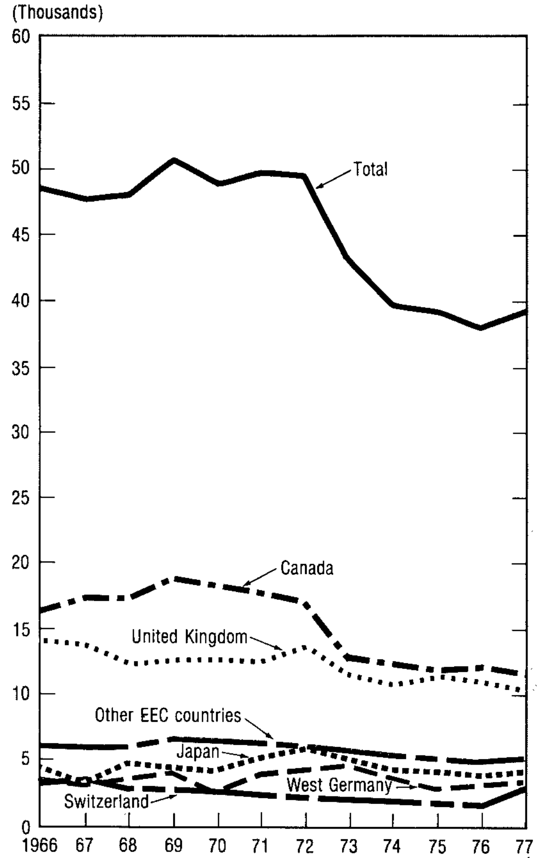
Since 1963, inventors from West Germany have received 79,343 U.S. patents, 25 percent of all foreign-origin patents. West Germany ranked first in 10 of the 15 product fields and second in the remaining 5 fields. Over half (58 percent) of all West German patent activity in the United States was in the nonelectrical machinery and chemical industries.

Japan ranks second in the total number of U.S. patents granted to foreign inventors from 1963 to 1979. During this period, almost a fifth of all foreign-origin patents granted by the United States went to Japanese inventors, for a total of 61,943 patents. Japan has the largest number of foreign patents in four categories—food and kindred products; primary metals; communication equipment and electronic components; and professional and scientific instruments. (West Germany had been the foreign leader in this last field throughout the 1960's and mid-1970's.) Since 1970, Japan has dramatically increased its patent activity by over 100 percent in every product field. This finding is significant because it refutes the belief that Japanese R&D efforts are focused on specific technologies.

The United Kingdom was granted 46,253 U.S. patents over the period, and is third in foreign patenting activity in the United States. United Kingdom inventors are in first place in the field of petroleum and gas extraction and refining and second in the fields of fabricated metals and motor vehicles and other transportation.

Figure 1-9

Patents granted to U.S. inventors by selected countries



REFERENCE: Appendix table 1-16.

Science Indicators — 1980

U.S. Patenting Abroad

U.S. patenting activity abroad has declined considerably, both in terms of absolute numbers (see figure 1-9) and in the U.S. share of patents granted to all foreign inventors (see appendix table 1-16). From 1971 to 1977, U.S. patenting activity with its major trading partners[80] dropped 21 percent. In absolute numbers of patents, most of this decrease has been in Canada, the United Kingdom, and West Germany. Since 1971, the U.S. proportion of all foreign patenting has declined from 65 percent to 61 percent in Canada,[81] and from 45 to 32 percent in West Germany. U.S. patents as a portion of all foreign-origin patents increased only in Japan, rising from 49 percent in 1971 to 51 percent in 1977.

The decline in foreign patenting activity by the United States may be partially due to the same factors which affect domestic patenting activity; that is, a decrease in U.S. inventive activity, an increased propensity to use trade secrets instead of patents to protect proprietary information, or low expectations of economic returns.

[80] West Germany, Japan, the United Kingdom, Switzerland, Canada, Belgium, Denmark, Ireland, Luxembourg, and the Netherlands. Comparable data for Italy are not available. Patents granted by France are not included because of wide fluctuations in French patents granted to foreigners.

[81] This reduction may have been caused indirectly by new controls placed on foreign companies in Canada. The high degree of U.S. patent activity in Canada has been influenced by the amount of U.S. direct investment and previous relative ease of obtaining a patent in Canada.

Another plausible influence on international patenting is the advent and spread of multinational corporations. U.S.-based multinational companies may opt to patent in the United States or have their subsidiaries patent abroad. In the latter case, the U.S. subsidiary assumes the nationality of the host country and the patent is registered as a domestic patent of that country. In addition, some of the factors that have made patenting in the United States attractive may act as deterrents to foreign patent filing by U.S. companies. For instance, the United Kingdom, West Germany, Switzerland, and the Netherlands require that patents be renewed by the payment of maintenance fees after an initial period; some countries have requirements that patents must be used domestically or rights to them be relinquished; British patent law requires that a patent must be worked within 3 years of issue if it is to remain in force; and obtaining and maintaining patents in some countries may be too expensive, given the small market in which the patent is protected.[82]

The decline in U.S. patenting activity abroad may also be partly due to low expectations of economic activity. There may be less demand in Europe and Japan for the type of products and processes that U.S. industry has been providing due to increased competition from indigenous industries in these countries and changing innovation needs in world markets[83] (see the discussion in the next section of this chapter).

Multiple patent filing abroad peaked in 1973-74 for almost all technology groups.[84] Patent documents issued by different countries which relate to the same invention can be grouped into a patent family. The average size of a patent family ranged between 1.3 and 3.7 from the mid-1960's to the mid-1970's. This means that essentially the same invention was patented abroad on the average in only two to three countries.

Since multiple patenting peaked in 1973, it probably is not a factor in the recent rise in foreign-origin patenting in the United States. The decrease in U.S. patenting abroad may be a part of a worldwide trend of declining multiple filing of the same invention. However, the U.S. proportion of patents granted to all foreign inventors has dropped in almost all the countries examined, indicating that U.S. inventors have reduced their foreign patenting to a greater extent than inventors of other nations (see appendix table 1-16).

In conclusion, since 1971, U.S. domestic patenting activity has declined in most product fields. Patenting activity by U.S. inventors has also decreased in most foreign countries. The factors which affect patenting activity tend to operate to different degrees in the various industries and countries. For example, trade secrets are thought to be used in rapidly developing fields where delay in patent granting reduces the value of patent protection, but not used when the invention is easily imitated once it reaches the marketplace, such as in the chemical fields. United States foreign direct investment (and thus the influence of multinational corporations on patenting activity abroad) is concentrated in the chemicals and machinery industries. Also, expectations of economic returns from foreign markets vary among countries (see appendix table 1-22). It is logical therefore, to expect patenting trends to vary among industries, product fields, and countries, but U.S. patenting activity has decreased in almost all product fields and in most countries. Thus, it is likely that there has been a decrease in the rate of U.S. inventions.

INTERNATIONAL TECHNOLOGY AND TRADE FLOWS[85]

During the two decades after World War II, the United States found itself in a unique position, enjoying one of the highest per capita incomes in the world, an abundance of raw materials, and the world's richest and largest domestic market. Capital supplies were relatively plentiful and inexpensive, while labor was relatively costly. This combination of circumstances gave U.S. industry the incentive to develop innovations which conserved on human labor—both in industry and in the home—and new consumer products designed for an increasingly affluent public.[86]

In Europe and Japan, a different situation existed.

[82] Some of these burdens were lifted with the signing of the Patent Cooperation Treaty in June 1970, which simplified the filing of patent applications on the same invention in different countries. The treaty went into operation in June 1978.

[83] See Vernon.

[84] Based on "Indicators of Patent Output of Industrialized Countries," Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, July 1980, a special report prepared for *Science Indicators* using data from the International Patenting Data Base of Derwent Publications Ltd. of London, United Kingdom.

[85] Much of this section is based on four papers by Jack Baranson, Edwin Mansfield, Nathan Rosenberg, and Raymond Vernon which were specially commissioned for *Science Indicators—1980* and will be published by the National Science Foundation in a report entitled, *Papers Commissioned as Background for Science Indicators—1980*, vol. I: Indicators of International Technology and Trade Flows, National Science Foundation, 1981. This introductory discussion of innovation patterns is based on the Raymond Vernon paper.

[86] Vernon.

Table 1-7. Product and process innovations introduced in U. S., Europe and Japan classified by their perceived advantages at time of introduction: 1945-1974

Perceived advantage at time of introduction	Number	Percent[1]
United States	826	100
Labor-saving	331	40
Material-saving	175	21
Capital-saving	58	7
Novel function	106	13
Safety	50	6
Multiple and other	106	13
Europe[2]	946	100
Labor-saving	120	13
Material-saving	444	47
Capital-saving	104	11
Novel function	83	9
Safety	60	6
Multiple and other	135	14
Japan	94	100
Labor-saving	6	6
Material-saving	32	34
Capital-saving	7	7
Novel function	12	13
Safety	7	7
Multiple and other	30	32

[1]Percents may not add to 100 because of rounding.
[2]The nine nations included are Belgium, France, Austria, Switzerland, Sweden, West Germany, Holland, Italy, and the United Kingdom.

NOTE: Based on a sample of 1,866 innovations from an international data bank jointly developed at the University of Sussex, OECD, and Harvard University. Each innovation was classified by its perceived principal factor-saving characteristics as seen by the innovating firm, the user, and industry/market observers. All innovations were selected by the criterion of commerical employment of the innovation by two or more independent firms anywhere in the world. The sample covers all broadly defined manufacturing industries except for the pharmaceutical and cosmetic industries, which were excluded because their factor-saving qualities could not be assessed and because the impact of U. S. Government regulations encourages U. S. drug companies to introduce new drugs abroad.

SOURCE: Raymond Vernon in "Gone are the Cash Cows of Yesteryear," *Harvard Business Review* September/October, 1980, adapted from W. H. Davidson, "Patterns of Factor-Saving Innovation in the Industrialized World," *Europe Economic Review*, vol. 8, 1976, pp. 214-215.

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These regions were recovering from a war that had destroyed much of their industrial plant; prices for capital and raw materials were high; their internal markets were smaller and per capita income levels were lower than in the United States. Responding to these factors, industries in these countries generally aimed many of their innovations at saving capital and materials, and producing lower-cost versions of U.S. innovations.[87] This concentration can be seen in table 1-7 which presents differences in the intended objective or advantage of a sample of innovations.[88] Each innovation was classified by the nation of initial commercial introduction, even if the innovating firm was a foreign subsidiary, under the hypothesis that the local conditions were the stimulation leading to the innovation. In a sample of 1,866 innovations introduced over the period 1945-74, 40 percent of the U.S. innovations were perceived as laborsaving, compared to only 13 percent in Europe and 6 percent in Japan. Materialsaving and capitalsaving innovations were much more important for these latter two, representing 58 percent of Europe's and more than 40 percent of Japan's innovations.

The circumstances in Europe and Japan during the post-World War II decades gave U.S. innovators a distinct advantage: As the foreign economies grew, income and wage levels rose relative to the costs of capital and materials. Thus, "innovation needs" in these countries began to resemble more closely those of the United States. Because foreign economies and consumer tastes followed the U.S. patterns, U.S. firms could concentrate on developing new processes and products for the U.S. domestic market with the assurance that these innovations and products would be in great demand in the future to the "follower markets" abroad. U.S. firms consequently earned high licensing fees from foreign users, filed extensively for foreign patents on their U.S. inventions, and increased export activities. U.S. firms may have tended to ignore foreign innovations on the assumption that they were not relevant to conditions in the United States.[89]

For the most part, the U.S. advantage has now greatly disappeared. Per capita incomes and wages in Europe and Japan no longer lag far behind those of the United States and in some cases equal or surpass them. Consumer demands have become similar, and the success of the European Economic Community has unified and enlarged foreign markets. In addition, the differences in cost structures that had distinguished the countries disappeared. As U.S. dependence on foreign sources for raw materials and energy grew, the historical U.S. advantage in the cost of such materials deteriorated. Global inflationary pressures began to influence the cost of capital everywhere and the traditional U.S. advantage in capital costs also largely evaporated. American business now confronts world markets that place a greater demand for the conservation of energy, materials, and capital. As a result, some analysts believe that the traditional U.S. emphasis on laborsaving innovations may no longer be as relevant or in demand in domestic and international markets as the European and Japanese capitalsaving and materialsaving emphases. This

[87]Ibid.

[88]These data are taken from W.H. Davidson, "Patterns of Factor Saving Innovation for the Industrialized World," *European Economic Review*, vol. 8 (1976), pp. 207-217. This study supports the idea that relative factor costs and (product and process) innovation are related.

[89]Vernon. See also appendix tables 1-16, 1-18, 1-24 for trends depicting U.S. technological transactions abroad.

is a relatively new challenge for the American entrepreneur.[90] Laborsaving innovations, however, may be increasingly important to developed nations' industries in the future. Economic competition is expected to increase from rapidly industrializing countries such as Brazil, Mexico, Taiwan, and South Korea. These countries have a labor-cost advantage which some analysts feel bodes ill for labor-intensive manufacturing plants in developed countries.[91]

International technological and economic competition has increased and has heightened concern over the international transfer of industrial technology by U.S. firms and the impacts of this diffusion upon U.S.-based production and industrial products.[92] To shed light on technology transfer issues, this section will deal with the extent and direction of technology flows and channels of transfer.

The proponents of technology transfer restrictions claim that the overall impact of such transfers on the United States is negative and results in lost jobs and market opportunities.[93] The transfer of some technologies to the Soviet Union, China, and Eastern Europe is also thought to be detrimental to the U.S. strategic position.[94] Those favoring the unrestricted transfer of technology and free trade argue that it is impossible to restrict the flow of information and technology, and that if the United States does not provide requested services and products, other countries will gladly do so and benefit from the sales.[95]

Other points often raised in support of the importance of technology transfer are the belief that the United States may be beginning to have a comparative advantage in exporting scientific and technical expertise in lieu of goods, and the fact that foreign direct investment often creates new markets that are sometimes inaccessible to export trade due to import restrictions, particularly in light of the success of market alliances such as the European Economic Community and Andean Pact. The establishment of an overseas subsidiary often creates a market pull situation, facilitating the sale of a variety of U.S. exports into that market because of the greater visibility of the company, and availability of faster maintenance and service.[96] Additionally, studies have shown that sales abroad help to finance domestic R&D and the development of new products.[97] Also, Government regulations may inhibit domestic innovation and encourage U.S. firms to conduct R&D abroad, particularly in the pharmaceutical industry. When "foreign" innovations are then introduced back into the United States, such transfers can provide benefits from the consumer standpoint.[98]

The negative and positive impacts of technology transfer will not be adjudicated here. At present, the magnitude and significance of technology transfer cannot be accurately assessed. Strictly defined, a technology has been transferred only when effectively applied by the recipient.[99] However, because of the enormous difficulties in determining the actual utilization of the technology, measures of what may be more properly termed tech-

[90] Raymond Vernon, "Gone are the Cash Cows of Yesteryear," *Harvard Business Review*, vol. 58 (November-December 1980), pp. 151-153.

[91] Japan is particularly concerned about economic competition from developing countries. See Peter F. Drucker, "Japan Gets Ready for Tougher Times," *Fortune*, vol. 102 (November 3, 1980), pp. 108-114.

[92] *Export Policy: Part 7—Oversight on U.S. High Technology Exports* (appendix paper "Technology Transfer: A Review of the Economic Issues," pp. 317-64), Subcommittee on International Finance, U.S. Congress, 95th Congress, Second Session Hearing, 16 May 1978; *Technology Trade*, Joint Hearings of the House of Representatives, 96th Congress, Second Session, June 24-26, 1980.

[93] Elizabeth Jager, "Trends in the Industrial Sector," Session on International Trends in Applying Science and Technology Problems, Opportunities and Policies, American Association for the Advancement of Science, Annual Meeting, Washington, D.C., February 14, 1978; *U.S. Technology DOD Perspective: A Report of the Defense Science Board Task Force on Export of Technology*, Department of Defense, 1976; J. Baranson, *Sources of Japan's International Competitiveness in the Consumer Electronics Industry* (Washington, D.C.: DEWIT, June 1980).

[94] Several thorough studies have been done on the topic of technology transfer to communist countries. See *Technology and East-West Trade*, Office of Technology Assessment (OTA-ISC-101), November 1979; Donald W. Green and Herbert S. Levine, *Implications of Technology Transfers for the U.S.S.R.* (Menlo Park: SRI International, 1977); and "Transfer of Technology to the Soviet Union and Eastern Europe," Hearing before the Permanent Subcommittee on Investigations, Committee on Government Affairs, U.S. Senate, May 25, 1977.

[95] *Factors Affecting the International Transfer of Technology Among Developed Countries*, U.S. Department of Commerce, 1970; Lowell W. Steele, Statement before Joint Hearings of the Subcommittee on Banking, Housing, and Urban Affairs and the Subcommittee on Science, Technology, and Space of the Committee on Commerce, Science, and Transportation, U.S. Senate, May 16, 1978; *Technology Transfer and the Developing Countries* (Washington, D.C.: U.S. Chamber of Commerce, 1977).

[96] Rosenberg.

[97] Edwin Mansfield, "Returns from Industrial Innovation, International Technology Transfer, and Overseas Research and Development," *NSF Colloquium on the Relationship Between R&D and Returns from Technology*, May 21, 1977, National Science Foundation; Edwin Mansfield, Anthony Romeo, and Samuel Wagner, "Foreign Trade and U.S. Research and Development," *The Review of Economics and Statistics*, vol. 61, (February 1979), pp. 49-57.

[98] Rosenberg.

[99] *Report of the Ad Hoc Meeting of Experts on the Measurement of International Technology Flows*, United Nations Economic and Social Council (SC. TECH./AC.33/26) February 24, 1977, p. 2.

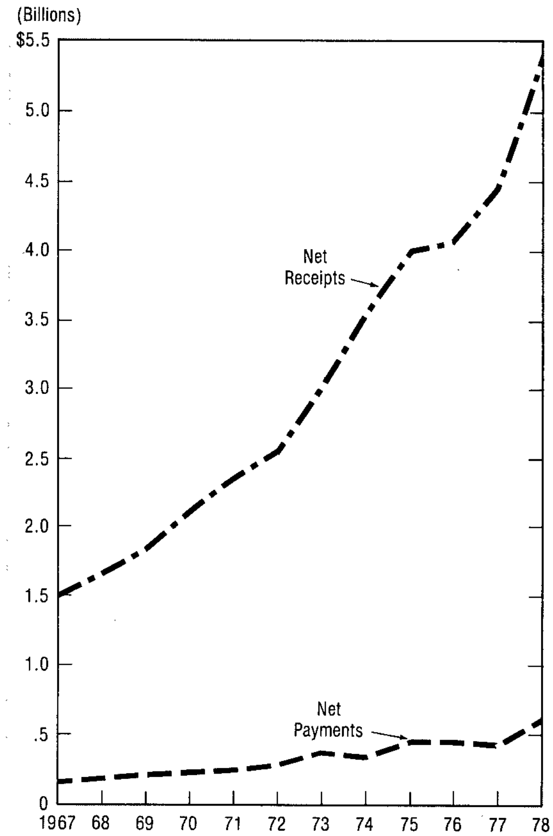
nology and information flows will sometimes be presented as indicators of technology transfer. While all the indicators in the following discussion have limitations as measures of technology transfer, considered together they can present a picture of what is occurring in U.S. technology transfer transactions abroad.

Technological products and information can be diffused or transferred in a variety of ways. The unobstructed exchange of scientific and technical literature is one of the main channels of information transfer. Exchange of technological know-how through personal contacts—including training of personnel, permanent or temporary immigration and emigration of scientists and engineers, and attendance at technical meetings and conferences—is another important means of transfer.[100] Embodied technology is exchanged in the form of exported or imported goods and services. A holder of a patent or trademark may license the use of this proprietary information to another party, or a firm may make a direct capital investment in another country and transfer technology to its subsidiary. Industrial technology transfer, which is the major emphasis in this chapter includes transmission, adjustment (including redesign of products and reengineering of production methods or processes), and implantation (including training of people, run-in of plant equipment, and setting up of related management and control systems).[101] This section deals primarily with technology flows related to foreign direct investment, licensing agreements, and R&D-intensive trade, since these are the major channels for the transfer of U.S. industrial technology.

Royalties and Fees

Data on international transactions in royalties and fees are frequently used as indicators of technology transfer. Royalties are payments for the use of copyrights or trademarks; licensing fees are charges for the use of a patent or industrial process. U.S. transactions are categorized into those associated with direct investment (for example, agreements between a U.S. company and its subsidiary abroad) and those which take place between independent organizations, referred to as "unaffiliated transactions."

Figure 1-10
U.S. international transactions in royalties and fees



NOTE: Data for 1978 are preliminary.
REFERENCE: Appendix table 1-18.
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Figure 1-10 presents international transactions on royalties and fees and shows that the United States sells about nine times more technology than it buys. Since 1967, total U.S. receipts have increased 258 percent (12.3 percent average annual rate) and reached a level of $5.4 billion in 1978.

Over 80 percent of the transactions take place between U.S. firms and their subsidiaries abroad. Net receipts from these affiliated firms have grown faster since 1967 than from unaffiliated sources (13.1 percent average annual increase compared to 9.5 percent, respectively). This concentration in technology transfers related to direct investment suggests that U.S. companies prefer to make transfers to affiliated companies, where they can protect their competitive positions by maintaining equity interest in the use of their intangible property and proprietary knowledge. The growth in

[100] See the section of this chapter entitled, "Cooperation and Interaction," for discussion of some of these types of people-oriented exchanges.

[101] Jack Baranson, "Critique of International Technology Transfer Indicators, *Papers Commissioned as Background for Sciences Indicators—1980*, vol. I:" *Indicators of International Technology and Trade Flows*, National Science Foundation, 1981.

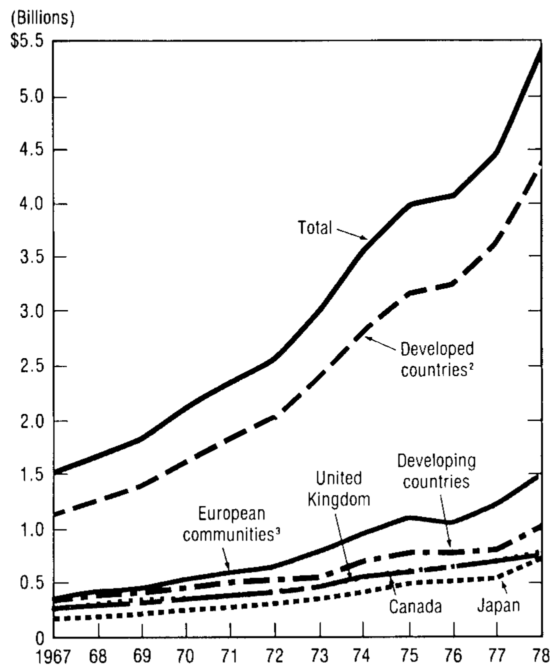
direct investment-related receipts took place largely in the machinery industry and in the chemicals and allied products industries. Affiliates in these industries are often provided with "front-end" technology, such as the latest innovations in the use of computers, semiconductors, integrated circuits, and advanced techniques in chemical production.[102]

In 1978, the United States purchased $610 million worth of technical know-how, 80 percent of which came from European sources. Like U.S. industry's technology transfers, foreign companies transferred their technology most often to their U.S. subsidiaries; 65 percent of U.S. payments are related to direct investment by foreign firms.

[102] Meryl L. Kroner, "U.S. Transactions in Royalties and Fees, 1967-78," *Survey of Current Business*, vol. 60 (January 1980), p. 30.

Figure 1-11

U.S. receipts of royalties and fees from selected nations



[1] Represents net receipts of payments by U.S. firms from both their foreign affiliates and unaffiliated organizations for the use of intangible property such as patents, techniques, processes, formulas, designs, trademarks, copyrights, franchises, manufacturing rights, management, etc. Excludes film rentals which are included in the royalties and fees data in the international transaction tables of the *Survey of Current Business*.

[2] Developed countries included here are Western Europe, Canada, Japan, Australia, New Zealand, and the Republic of South Africa.

[3] Original six members only.

NOTE: Data for 1978 are preliminary.

REFERENCE: Appendix table 1-19. Science Indicators—1980

U.S. payments for technology normally consist of a small number of relatively large transactions, in contrast to U.S. receipts for sales of technical information, which typically consist of a large number of transactions of various sizes.[103] This may mean that the United States is importing very specific and specialized technologies while exporting technology in a great variety of areas.

U.S. technology has been purchased primarily by industrialized countries; over 80 percent of U.S. technical know-how transferred through licensing agreements was to developed nations in 1978 (see figure 1-11). In that year, Canada, the United Kingdom, and Japan each received about 15 percent (or together, almost half) of the U.S. technology transferred. Over the 10-year period since 1968, the proportion of U.S. technology going to Europe decreased to 32 percent while the share transferred to Japan increased. The proportion of U.S. technical know-how being sent to developing countries has decreased over the decade from one-fourth of all sales to 20 percent.

There are differences between countries in the preferred form of transactions. Most of the U.S. technical know-how transferred to Canada and developing countries is through U.S. subsidiaries (92 percent and 85 percent, respectively, in 1978). In contrast, Japan has traditionally purchased U.S. technology through unaffiliated sources, since direct investment has been discouraged by the Japanese Government. However, direct-investment transactions have increased in importance due to a liberalization of Japanese policy toward foreign capital inflow that occurred in the early 1970's.[104] In 1967, unaffiliated transactions represented 72 percent of the Japanese total, but by 1978, their share was less than half (46 percent). However, a significant portion (one-third) of all U.S. unaffiliated technology transfers are to Japan. There is likely to be less control over the utilization of technology transferred to an independent party than to a subsidiary.

In terms of technology transfers by types of industry, many of the latest developments in U.S. technology in the areas of computer and advanced electronics industries were provided to foreign affiliates in Germany, France, the United Kingdom, Japan, and Canada. Over 70 percent of the chemical technology transactions is direct-investment related.

[103] Ibid., p. 34.

[104] Consultations with Dr. Terutomo Ozawa, Professor of International Economics, Colorado State University, and with representatives of the Japanese Embassy, Washington, D.C. See also Terutomo Ozawa, *Multinationalism Japanese Style: A Political Economy of Outward Dependency* (Princeton: Princeton University Press, 1979).

U.S. technology in agricultural chemicals and fertilizers is generally transferred to subsidiaries in Canada and France; technologies in industrial chemicals, plastics, and synthetics are transferred to affiliates in the United Kingdom and West Germany; and pharmaceuticals technologies to affiliates in West Germany and France. Most of the unaffiliated transactions in chemical technologies are with developing countries and are chiefly in the areas of industrial and agricultural chemicals and pharmaceuticals.[105]

These receipts and payments data for international transactions are only a rough and partial measure of international technology flows for a number of reasons. Much technology crosses national borders freely without involving monetary payment, or is not paid for separately because it is part of a larger transaction or operation. In direct investment-related transactions (80 percent of total) the amount of the charge is likely to be influenced (perhaps inflated) by corporate decisions other than the actual value of the technology concerned, for instance, tax considerations. In unaffiliated transfers, the charge for the technology may underrepresent its true value because receipts and payments data do not reflect other means of augmenting the price of the technology, such as tie-in sales agreements to purchase intermediate goods from the licensing firm or the exchange of rights to other technologies or technical assistance.[106]

Several other caveats should be mentioned. The data include receipts and payments for transactions not strictly involving technology: for example, a considerable part of these royalties and fees are for access to trademarks (although trademark rights are usually tied to quality control restrictions on production processes and so are linked to technology). Because payments are usually spread over time, data for any given year reflect returns on cumulative, as well as annual, transfers. However, because payments are usually proportional to use, current payments do provide some measure of the current use of transferred technology.

Some limitations of the royalties and fees data discussed here tend to overestimate the value of the technology transferred, while others underestimate the value. It is difficult to say with certainty where the balance lies. Nonetheless, licensing agreements do represent one of the major channels through which technical information flows and royalties and fees data provide an indication of the direction of such flows. Research efforts on adequate measures of technology transfer are in their infancy; much more needs to be done in this problematic area. Currently it is difficult to interpret what the net increase in U.S. licensing transactions really means. But when these trends are examined in conjunction with the other indicators of technology flows—all of which show that the United States is a net exporter of technological information and products[107]—it is possible to have greater confidence that they actually represent increased outflows of technical information from licensing agreements.

Direct Investment Abroad

Another method of transferring technology is through establishing overseas subsidiaries. Many firms have decided to become "multinational" in order to exploit a technological lead or because foreign import restrictions make the establishment of overseas production facilities the only viable way a firm can introduce its products into a foreign market. Although it is difficult to determine how much technology is transferred through direct-investment activities abroad, multinational firms do transfer technology in a variety of ways. They train technicians and managers, communicate information and capabilities to engineers and technicians, help client companies use their products more effectively, and assist suppliers to upgrade their technologies.[108] Furthermore, the extent of direct investment abroad greatly affects the amount and value of licensing agreements (see previous section) and the amount of U.S. R&D performed abroad.

U.S. direct investment abroad has grown steadily throughout the years. Appendix table 1-22 shows that in manufacturing industries, U.S. investment abroad reached a level of $74.2 billion in 1978. This amount is representative of the level of investment, not a measure of technology transfer. Half of all U.S. manufacturing direct investment abroad occurs in the machinery and chemical industries, both of which are R&D-intensive. Over 80 percent of U.S. manufacturing investment abroad is in industrialized countries, especially in Canada, the United Kingdom, West Germany, and (to a lesser degree) France

[105] Kroner, p. 32.

[106] Edwin Mansfield, "International Technology and Trade Flows," *Papers Commissioned as Background for Science Indicators—1980, vol. I: Indicators of International Technology and Trade Flows*, National Science Foundation, 1981.

[107] For a discussion of how these indicators can be used, see S. Okubo, "The Impact of Technology Transfer on the Competitiveness of U.S. Producers," in *Study of U.S. Competitiveness*, submitted to the Interagency Analytical Group to Study Competitiveness of U.S. Producers, July 15, 1980.

[108] Mansfield.

The production of technology-intensive products abroad has increased through the growth of U.S. investment abroad. Recent findings show that the rate of spread of U.S. multinationals over the period 1945 to 1975 reached a peak in the late 1960's, although high growth continued through the first part of the 1970's. There was a marked speedup in the spread of foreign production of new products through subsidiaries. The period between U.S. introduction and initial transfer shrank rapidly over the period 1945 to 1975.[109] Table 1-8 gives some evidence that R&D-intensive firms were moving the production of their new products abroad at a faster rate than firms with lower R&D intensities. This is true whether R&D intensity was measured in terms of the industry of the parent firm, or the relative R&D-intensive position of the firm in its industry. (See appendix table 1-23.)

These R&D-intensive firms eventually introduced a higher percentage of their total products abroad and had higher average annual transfer rates. This is consistent with the general proposition that the propensity of firms to trade or produce abroad is associated with a perception that they will enjoy unique competitive advantages in the market in which they plan to operate.[110]

U.S. R&D Performed Abroad. Another measure of international technology flow is the amount of R&D performed abroad by U.S. subsidiaries. As shown in table 1-9, since 1975 the amount of R&D conducted by U.S. affiliates has increased 88 percent, reaching a level of $2.7 billion in 1979, which was equal to 11 percent of U.S. domestic industry's R&D funds. In each of these 5 years, foreign R&D expenditures by U.S. industry increased more rapidly than domestic company funds. In 1979, large increases in R&D expenditures in the aircraft and missiles, scientific instruments, electrical equipment, and chemicals industries led to a 23 percent average annual growth rate for total R&D performed abroad—the highest over this period. Many of these increases were basically product adaptions in response to local market needs and opportunities.[111] R&D performed abroad by the U.S. chemical industry increased 67 percent from 1975 to 1979. Government regulation is often viewed as

[109] Raymond Vernon and W.H. Davidson, *Foreign Production of Technology- Intensive Products by U.S.-based Multinational Enterprises,* National Science Foundation, 1979, pp. 8-13, 36-45. These findings are based on two new data bases. One set of data consists of a sample of 180 U.S.-based multinational enterprises. The data include a record of the specific product lines manufactured in each subsidiary. Another new set of data traces the spread of production of 406 innovations introduced in 1945 or thereafter by 57 U.S.-based multinational enterprises. In addition, 548 "imitations" (in the sense that they were new to the introducing firm but closely resembled the innovations of other firms) were also traced. The imitations data trends generally parallel the innovations data trends; the spread abroad of innovations was only slightly more rapid and extensive.

[110] Ibid., pp. 55-58.

[111] "Greatest Increase in 1978 Industrial R&D Expenditures Provided by 14% Rise in Companies' Own Funds," *Science Resource Studies Highlights,* National Science Foundation (NSF 80-300), pp. 3-4; *Research and Development in Industry, 1978,* National Science Foundation (NSF 80-307), p. 16; NSF unpublished statistics.

Table 1-8. Transfers of innovations by U.S.-based multinational enterprises[1] to their manufacturing subsidiaries abroad by R&D intensity of the parent: 1945-77

Innovations classified by parent's R&D expenditures as percent of sales	Number of innovations	Percentage transferred abroad, by number of years between U.S. introduction and initial transfer: Less than 2 years after	2 or 3 years after	4 or 5 years after	6 to 9 years after	10 or more years after	Total	Average annual transfer rate from year of first foreign introduction to: 3rd year thereafter	1977 year end
Under 2 percent	108	22.2	12.1	15.7	13.0	14.7	77.7	.803	.349
2 to under 4 percent	190	14.7	16.3	10.0	16.3	21.6	78.9	1.003	.293
4 percent and over	108	22.2	20.4	11.1	13.0	22.2	88.9	1.067	.331
Total	406	18.7	16.3	11.6	14.3	20.2	81.1	1.017	.326

[1] Transfers of 406 innovations by 57 U.S.-based multinational enterprises.

REFERENCE: Appendix table 1-23.

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Table 1-9. Company R&D performed abroad by foreign affiliates of U.S. domestic companies by selected industry

[U.S. dollars in millions]

Industry	1975	1979	Percent increase
Total	$1,441	$2,709	88
Food and kindred products	23	52	126
Chemicals and allied products	269	450	67
Industrial and other chemicals	85	(1)	NA
Drugs and medicines	184	269	46
Stone, clay and glass products	7	(2)	NA
Primary metals	9	14	56
Fabricated metals	(2)	35	NA
Machinery	331	542	64
Electrical equipment	232	475	105
Electronic components	7	24	242
Other Electrical equipment	(1)	15	NA
Transportation	412	845	105
Motor vehicles and other transportation equipment	373	(1)	NA
Aircraft and missiles	39	127	226
Professional and scientific instruments	49	87	78
Other manufacturing industries	105	204	94
Nonmanufacturing industries	4	4	0

[1]Not separately available but included in higher level total.
[2]Included in the other manufacturing industries group.

NA = not available.

SOURCE: National Science Foundation, *Research and Development in Industry, 1979* (Detailed Statistical Tables) (NSF 80-307), p. 16, and National Science Foundation, unpublished statistics.

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one of the primary factors leading to this increase and is blamed for slowing the rate of introduction of new pharmaceutical products into the United States.[112] Regulatory changes can create an environment of uncertainty and inconsistency which inhibits investment and innovation. Excessive amounts of documentation required for compliance with some of the regulations can also be a deterrent.[113] A recent OECD study found that, despite a considerable increase in pharmaceutical R&D over the past 15 years, the number of new chemical entities marketed in the United States and Europe fell by about half between 1960 and 1973.[114] It was estimated that the cost of testing and developing a major new pharmaceutical product increased from about $1.2 million in 1962, to $24 million in 1974, to $54 million in 1976, and to an estimated $100 million in 1980. Similar trends were found for pesticides. In both product groups, there were increases in the number of substances tested per innovation and in the length of the period required for testing and approval.

Foreign R&D Performed in the United States

Does foreign investment in the United States result in an outflow of U.S. technology to other

[112]Louis Lasagna, William Wardell, and Ronald Hansen, *Technological Innovation and Government Regulation of Pharmaceuticals in the United States and Great Britain*, National Science Foundation, 1978.

[113]*The Impact of Regulation on Industrial Innovation* (Washington, D.C.: National Research Council, 1979), pp. 8-34.

[114]*Science and Technology in the New Socio-Economic Context*, p. 68; *Impact of Multinational Enterprises on National Scientific and Technical Capabilities: Pharmaceutical Industry* (Paris: OECD, 1977), pp. 267-271.

Table. 1-10. R&D expenditures by U.S. affiliates of foreign companies

[U.S. dollars in millions]

Country and industry	Expenditures 1974	Expenditures 1977	Percent change
By country of foreign parent			
Total	$813	$898	10
Developed countries	694	742	7
Canada	53	57	8
Europe	611	653	7
France	14	27	93
West Germany	46	98	13
Netherlands	285	230	−19
United Kingdom	107	125	17
Switzerland	140	154	10
Other	19	31	63
Japan	29	19	−34
Developing countries	119	156	31
Latin America	117	153	31
Other	3	3	—
By industry of U.S. affiliate			
Total	$813	$898	10
Petroleum	111	111	—
Wholesale trade	78	33	−58
Manufacturing	574	709	23
Food and kindred products	NA	27	NA
Chemicals and allied products	NA	461	NA
Primary metal and industries	NA	18	NA
Fabricated metal products	NA	20	NA
Nonelectrical machinery	NA	51	NA
Electrical and electronic equipment	NA	86	NA
Other manufacturing	NA	45	NA
Other industries	50	45	−10

NOTE: Detail may not add to totals because of rounding.

SOURCE: Department of Commerce *Foreign Direct Investment in the United States, Vol. 1,* "Report of the Secretary of Commerce to the Congress," 1976, p. 54; Ned G. Howenstine, "Selected Data on the Operations of U.S. Affiliates of Foreign Companies, 1977," *Survey of Current Business* (July 1980), p. 43.

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nations? While there have been cases in which foreign firms have purchased American companies and thereby gained access to U.S. technology which was subsequently transferred abroad, studies have concluded that foreign companies more often invest in the United States to take advantage of the large, politically unified, and stable market than to have access to U.S. technology.[115] In order to compete successfully, foreign firms usually introduce their most sophisticated technologies and new management techniques, thus, the United States probably receives a net technological benefit from foreign investment.

Foreign-owned U.S. affiliates expended $898 million on R&D in 1977, up 10 percent from the 1974 level. Table 1-10 shows that about three-quarters of this R&D was conducted by European-owned affiliates. About 80 percent of foreign R&D spending was in manufacturing—two-thirds of which was in chemicals and almost one-fifth in machinery industries.

Trade in R&D-Intensive Manufactured Products

R&D-intensive trade data also have some limitations as measures of technology transfer. Because very little technology may be transferred in the export of a large volume of a product produced by a complicated and superior process not discernible

[115] *Technology Transfer from Foreign Direct Investment in the United States* (Washington: National Research Council, 1976); W. Halder Fisher, *Technology Transfer as a Motivation for United States Direct Investment by European Firms* (Columbus, Ohio: Battelle Memorial Institute, 1977).

from the product alone, trade statistics may overstate the level of technology transferred. On the other hand, a small volume of exports may transfer a great deal of technology if the product is highly advanced technologically and easy to copy. In some cases, (for example, the export of advanced computers) the mere availability of a product in a foreign country may result in the transfer of technology, since the product may provide the country with new technological information or capability. The importing country may also gain technology because the exporter will help the country to use the product efficiently; by training workers to use, maintain, or repair equipment, for example.[116] In view of these uncertainties and because factors other than technology also influence trade, R&D-intensive trade data are only partial or indirect measures of technology transfer. Nonetheless, trade is an important channel through which technology flows, and these data are important as S&T economic impact indicators.

Although it is generally accepted that technology plays an important role in U.S. trade,[117] it cannot necessarily be assumed that increased R&D expenditures will improve the U.S. trade position. In fact, since industries are linked in various ways (e.g., through interconnected markets for productive factors, behavior of exchange rates, and endogenous elements of U.S. and foreign commercial policies), R&D activities may improve the competitive position of one industry while aggravating or causing economic problems in other industries; for example, by diverting capital and labor and forcing up the price of some productive factors. However, increased R&D in one industry can also have positive spillover effects to other industries by providing superior and/or lower-cost inputs.[118] Increased R&D can also have a positive effect on the overall economy by generating new industries and forcing stagnant industries to become more dynamic or to tighten their operations.

U.S. trade in manufacturing products can be examined by product categories classified by relative levels of R&D investment. R&D-intensive product fields are defined here as those associated with industries with an average of 25 or more scientists and engineers engaged in R&D per 1,000 employees and total R&D funding amounting to at least 3.5 percent of net sales. The product groups designated as R&D-intensive are:[119] (1) chemicals, (2) machinery (electrical and nonelectrical), (3) aircraft and parts, and (4) professional and scientific instruments.[120]

Although the overall U.S. trade balance has shown large deficits in the last several years ($24.5 billion in 1979) figure 1-12 shows that the trade balance for R&D-intensive manufactured products has been positive for the past two decades. This positive balance has increased dramatically since 1972, reaching $39.3 billion in 1979. In sharp contrast, non-R&D-intensive manufactured products have registered deficits through the past two decades; since 1972, the trade balance in these goods dropped

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[116] Mansfield.

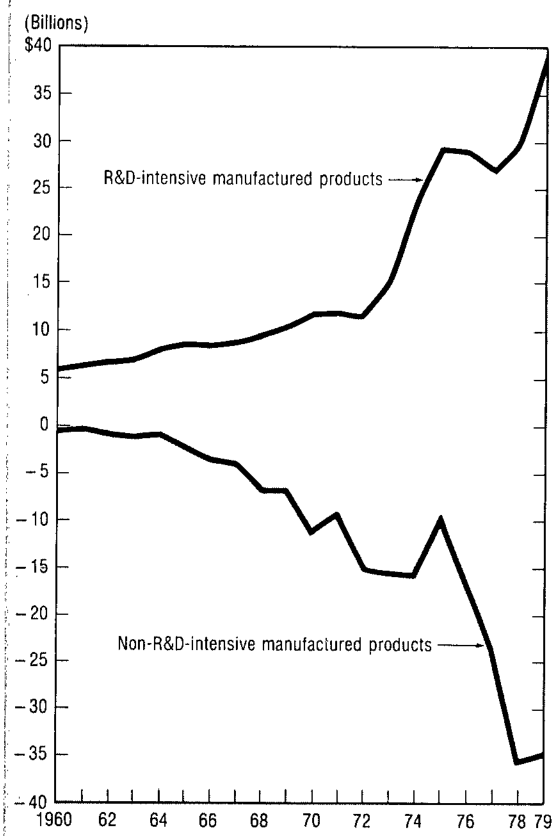
[117] Raymond Vernon, "International Investment and International Trade in the Product Cycle," *Quarterly Journal of Economics*, vol. 80 (May 1966), pp. 190-207; and Raymond Vernon (ed.), *The Technology Factor in International Trade* (New York: Columbia University Press, 1970).

[118] Rachel McCulloch, *Research and Development as a Determinant of U.S. International Competitiveness* (Washington, D.C.: National Planning Association, 1978), pp. 24-26.

[119] Products and industries, although fairly closely correlated at the gross level, do not perfectly coincide, with the result that not all products manufactured by a high-R&D performing industry can be considered R&D-intensive products. Examination of data on applied R&D by product field in manufacturing, however, shows that the fields considered here as R&D-intensive are among the top recipients of applied R&D expenditures, and from 78 to 92 percent of all U.S. R&D performed in these product fields is conducted by their associated industries. See *Research and Development in Industry, 1977,* National Science Foundation (NSF 79-313), pp. 56-57.

[120] Using this categorization of R&D-intensity, there is a natural break between industries. The automobile industry would be the next to be included, but ranks far below the other four industries in terms of concentration of R&D scientists. See *Research and Development in Industry, 1978,* National Science Foundation, (NSF 80-307) pp. 22, 32.
The Department of Commerce has developed two other classifications of R&D-intensive categories and the U.S. Department of Labor has recently developed its own. An analysis and comparison of them can be found in the *International Economic Report of the President,* Council on International Economic Policy, Executive Office of the President, 1977, pp. 120-124; Regina K. Kelly, "Alternative Measurements of Technology-Intensive Trade," *Staff Economic Report,* Office of Economic Research, Department of Commerce, 1976; C. Michael Aho and Howard F. Rosen, *Trends in Technology-Intensive Trade: With Special Reference to U.S. Competitiveness,* Office of Foreign Economic Research, U.S. Department of Labor, 1980.
The industry-based definition used here does have the disadvantage of including some products manufactured by R&D-intensive industries which are not themselves R&D-intensive and thus may tend to overstate somewhat R&D-intensive trade values. Product-based data circumvent this problem, but have the disadvantage of time delays in the availability of the data. Additionally, product mixes and product R&D intensities may vary across countries and time while industrial R&D intensities may be more consistent across time and countries. Although there are differences in level of aggregation and thus values, all of these categories essentially show the same trends.
A recent report looks at trade performance of various countries on the basis of a technology output proxy (patents/value added). See Luc Soete, "The Impact of Technological Innovation on International Trade Patterns: The Evidence Reconsidered," a paper presented at the OECD Science and Technology Indicators Conference, Paris, September 15-19, 1980.

Figure 1-12
U.S. trade balance[1] in R&D-intensive and non-R&D-intensive manufactured product groups



[1]Exports less imports.
REFERENCE: Appendix table 1-24.
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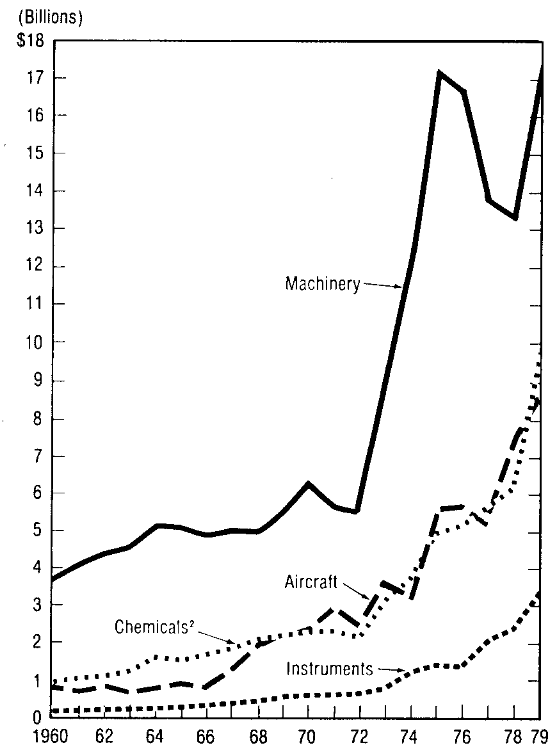
Figure 1-13
U.S. trade balance[1] in selected product groups



[1]Exports less imports.
[2]Includes drugs and other allied products.
NOTE: After 1977, the Commerce Department made revisions in the product group classifications which somewhat affected the balances of these product groups. The overall R&D-intensive balance was unaffected.
REFERENCE: Appendix table 1-25.
Science Indicators—1980

132 percent to a deficit of $34.8 billion in 1979. Most of the increased deficit was due to increases in imports of iron and steel mill products, as well as automobiles.

Figure 1-13 disaggregates the positive R&D-intensive trade balance by product group. Machinery products account for about half of the favorable balance. The phenomenal growth in the machinery balance from 1972 to 1975 (205 percent) occurred largely as a result of increased exports of electronic computers, internal combustion engines, construction equipment, and mining and well-drilling machinery. The sharp decline after 1975 is in part a result of large growth in imports of consumer electronic products, power machinery, and engines.[121] However, part of the decline is attributable to a number of revisions in the product group classifications by the U.S. Department of Commerce. To a great degree, these revisions also explain the recent growth in scientific and professional instruments. For instance, prior to 1977, electric measuring and controlling instruments were classified as machinery. Since 1977, they have been included in scientific and professional instruments.[122] Both the chemicals industry and the aircraft and parts industry contribute about one-fifth of the positive balance, with chemicals increasing this share to 25 percent in 1979. Since 1972, the positive trade

[121]Determined from data in *Overseas Business Reports*, Department of Commerce, July 1980, pp. 6-16.

[122]For the most part, these changes were between R&D-intensive manufactured product groups and do not affect the overall R&D-intensive manufactured trade balance of figure 1-12. For more detail, see appendix table 1-25 and U.S. Department of Commerce, *Overseas Business Reports*, OBR 79-22, August 1979.

balance in the aircraft and parts product groups has more than doubled, and that of chemicals products has more than trebled. The 64-percent increase in the aircraft and parts balance from 1977 to 1979 was mainly due to large increases in exports to the European Economic Community, Japan, and Canada.

As can be seen in figure 1-14, the United States enjoys a favorable balance of trade in R&D-intensive manufactured products with all our major trading partners except Japan and West Germany. The trade deficit with Japan began to increase dramatically after 1974. Over the period 1974-78, the deficit grew over 90 percent, reaching a level of $5.7 billion. This negative trade balance with Japan subsequently improved somewhat and in 1979 was -$4.3 billion. Exports to Japan have grown only slowly while imports soared—primarily in electrical machinery products such as consumer electronics. This deficit has caused concern over whether U.S. industry can remain internationally competitive in the fields of electronics and communication. Only in the areas of chemicals and aircraft and parts has the United States maintained a positive balance with Japan. In trade with West Germany, the United States has had deficits in chemicals and machinery while the trade balance in aircraft and professional and scientific instruments has been positive. The sharp depreciation of the U.S. dollar vis-a-vis the Japanese yen and the German Deutschemark through 1978 exacerbated the trade deficit by increasing the price of imports.[123]

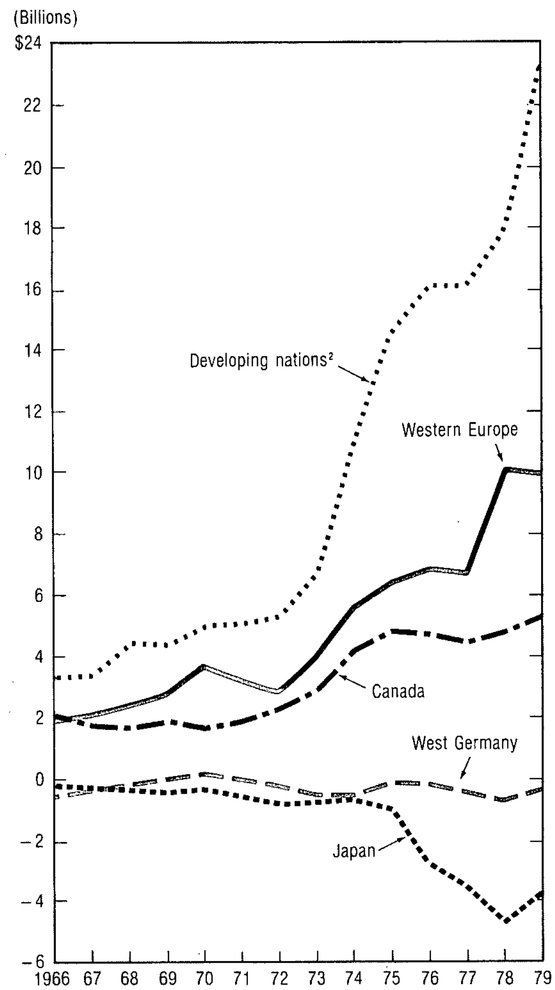
The developing countries accounted for over 60 percent of the overall favorable trade balance and 38 percent of the U.S. exports in R&D-intensive manufactured products. Machinery—especially nonelectrical—and chemical products were the two largest export groups to these countries. These same two product groups represent the largest U.S. exports in R&D-intensive manufactures to Western Europe as well.

In addition to the U.S. trade deficits in R&D-intensive manufactured products registered with Japan and West Germany, examination of world export shares shows some deterioration in the U.S. competitive position in these products. A recent study[124] concludes that relative to its major economic competitors, the United States still has a strong competitive and comparative advantage in R&D-intensive products, but that there has been some erosion in that position.

Table 1-11 shows that even though the United States still has the highest share of world exports of R&D-intensive manufactured products, the percentage dropped from 31 percent in 1962 to 21 percent in 1977. Most of the market loss occurred in the rapidly growing markets of developing countries, where the U.S. share decreased by almost half. If automobiles are included in the comparison, West Germany's share of R&D-intensive

Figure 1-14

U.S. trade balance[1] with selected nations for R&D-intensive manufactured products



[1]Exports less imports.

[2]Includes the Republic of South Africa in 1966 and 1967.

REFERENCE: Appendix table 1-26.

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[123] The yen substantially depreciated during 1979, which may have helped to bring some relief to the U.S. trade deficit with Japan. See *Economic Report of the President*, Council of Economic Advisors, 1980, pp. 174-183.

[124] Aho and Rosen. It should be noted that the R&D-intensive definition used in this study is product-based, and thus, more narrow in scope than the R&D-intensive definition used elsewhere in this report.

Table 1-11. Export market shares for R&D-intensive goods in developed and developing countries

	1962	1970	1977
United States			
DC[1]	20	22	17
LDC[2]	46	31	24
World	28	23	19
World w/o autos	31	27	21
Japan			
DC	3	8	14
LDC	6	15	22
World	4	10	16
World w/o autos	5	10	14
France			
DC	8	8	9
LDC	7	9	9
World	8	8	10
World w/o autos	7	7	8
Germany			
DC	26	21	22
LDC	11	12	14
World	21	19	20
World w/o autos	17	17	18
United Kingdom			
DC	17	9	7
LDC	15	12	9
World	17	10	8
World w/o autos	14	10	9

[1]DC = Developed Countries.
[2]LDC = Less Developed Countries.

SOURCE: C. Michael Aho and Howard F. Rosen, *Trends in Technology—Intensive Trade: With Special Reference to U. S. Competitiveness* Office of Foreign Economic Research, Department of Labor, 1980, pp. 48 and 55.

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exports both to the world and to developing countries was greater than that of the United States in 1977.[125] Japan showed the greatest gains over the period 1962-77, increasing its share of R&D-intensive exports from 5 percent to 14 percent. While much of the decline in the U.S. share of world markets in R&D-intensive products has occurred in the expanding markets of the developing countries, the Japanese share of technology-intensive exports to developing countries tripled over the period. Markets for R&D-intensive products are expanding, but U.S. firms are not entering and competing in the new expanding markets as effectively as the Japanese and West Germans.

Dissemination Mode of Technological Products and Information

The various channels through which technological products and information are transmitted are interrelated. For example, U.S. exports of a particular product may be replaced by foreign production of the product line by U.S. subsidiaries. Information on the relative importance of the various modes of technology transfer is helpful in interpreting trends

[125]Since 1975, the U.S. share of world exports (excluding exports to the United States) in total manufactured products also has declined slightly and was surpassed by West Germany in that year. *International Economic Indicators*, Department of Commerce, September 1980, p. 34.

Table 1-12. Percentage distribution of R&D projects,[1] by anticipated channel of international transfer during the first five years after commercialization: 1974-1979

Category	Channel of technology transfer: Foreign subsidiary	Exports	Unaffiliated licensing	Joint venture	Total
All R and D projects					
16 industrial firms	85	9	5	0	100
7 major chemical firms	62	21	12	5	100
Projects aimed at					
Entirely new products	72	4	24	0	100
Product improvements	69	9	23	0	100
Entirely new processes	17	83	0	0	100
Process improvements	45	53	2	1	100
Projects where estimated rate of return[2] is:					
Less than 20 percent	36	19	38	7	100
20 percent to 39 percent	46	29	19	5	100
40 percent or more	100	0	0	0	100

[1]Based on 1974 R&D projects of 23 U.S. firms.
[2]If commercialized.

SOURCE: Edwin Mansfield, Anthony Romeo, and Samuel Wagner, "Foreign Trade and U. S. Research and Development," *Review of Economics and Statistics*, (February 1979), p. 55.

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in technology flows. In particular, such information helps to assess more adequately whether or not the decline in the U.S. share of world exports of R&D-intensive manufactured products is critical.

A recent study obtained data on principal expected modes of transfer from a sample of 23 major U.S. firms for which returns from abroad were estimated to be of substantial importance.[126] Table 1-12 presents the distribution of R&D projects by the anticipated initial channel of international technology transfer during their first 5 years of commercialization. Although the traditional view is that exports are the first mode of international technology transfer, these findings indicate that in the first years after commercialization of the new technology, foreign subsidiaries are expected to be the most frequently used channel, followed by exports and licensing,[127] and finally by joint ventures. According to these data, product innovations are more likely to be transferred abroad via foreign subsidiaries of U.S. firms than are process innovations; while process innovations are not likely to be transferred except through exports of resulting products. This seems to be done in part to retain greater control of the use of processes and to guard against their unauthorized use. Table 1-12 also suggests that the most profitable innovations are transferred to subsidiaries while the marginally profitable innovations are more often licensed; many firms believe that unaffiliated licensing will give away valuable expertise to foreign producers who will become future competitors.

Firms seem to prefer direct investment to unaffiliated licensing when foreigners lack the knowledge to assimilate sophisticated technology or when a firm is concerned about protecting quality standards. Licensing is often preferred when the foreign market is too small to warrant direct investment, in countries where direct investment is discouraged by the Government or is risky, when the firm lacks the necessary resources to set up an overseas operation, or when there are advantages to cross-licensing.[128]

There appears to be variation among industries as to the mode of technology transfer preferred. OECD studies indicate that in the computers and advanced electronic components industry, the transferred technology (mainly of American origin) was sent to Europe during the 1960's and 1970's, half the time by licensing and half the time by direct investment, although in terms of dollar values direct investment was more important than licensing. In plastics, licensing and joint venture have been the principal modes of transfer. In pharmaceuticals, the most important channel is direct investment. These differences seem to be due to differences in the extent of the technological lead, competition, and specialization of firms in different product areas. Transferred technology in pharmaceuticals and plastics originated in both Europe and the United States.[129]

The age of a technology also influences the mode of transfer chosen. As is evident from figure 1-15, in the first 3 years following the introduction of an innovation, firms favor the subsidiary channel in over 90 percent of cases, while licenses gain in importance only 4 or 5 years after the introduction. These data are based on a study of 32 firms responsible for 221 innovations and 832 transfers of production overseas over the 1945-75 period. Of this total, only 20 percent of the transfers were through independent licenses, while the majority were transferred via subsidiaries. This supports the findings reported in table 1-12 that foreign subsidiaries are the most frequently used channel of technology transfer. These two studies do not support the conventional view that unaffiliated licensing has been increasing in importance as a transfer channel for U.S. products and processes. In fact, the importance of licensing declined from 31 percent of the transfers during 1944-54 to only 20 percent in 1966-75.[130] Also, there is evidence that foreign subsidiaries have become a more frequently used channel than exports for introducing R&D products abroad.

In order to assess the impact of international technology transfer on the U.S. economy, indicators of the value or usefulness of the transferred technology to the foreign recipient and the American consumer need to be developed. The role of market pull and the viability of alternatives to transfer should also be examined. Many of the indicators presented here measure the price charged to purchasers of technology but not the contribution of the technology to the productive output of the recipient. Determining the value of the technology from the receiver's viewpoint could provide insight into the potential competition resulting from the transfer. The usefulness of the technology is a function of its quality characteristics and of the effectiveness of the transfer process in

[126] It was stipulated that to be included in the sample, 10 to 25 percent of each project's total returns should come from abroad. See Edwin Mansfield, Anthony Romeo, and Samuel Wagner, "Foreign Trade and U.S. Research and Development," *Review of Economics and Statistics*, (February 1979), p. 55.

[127] Throughout this discussion "licensing" refers to licensing to firms not affiliated with U.S. firms.

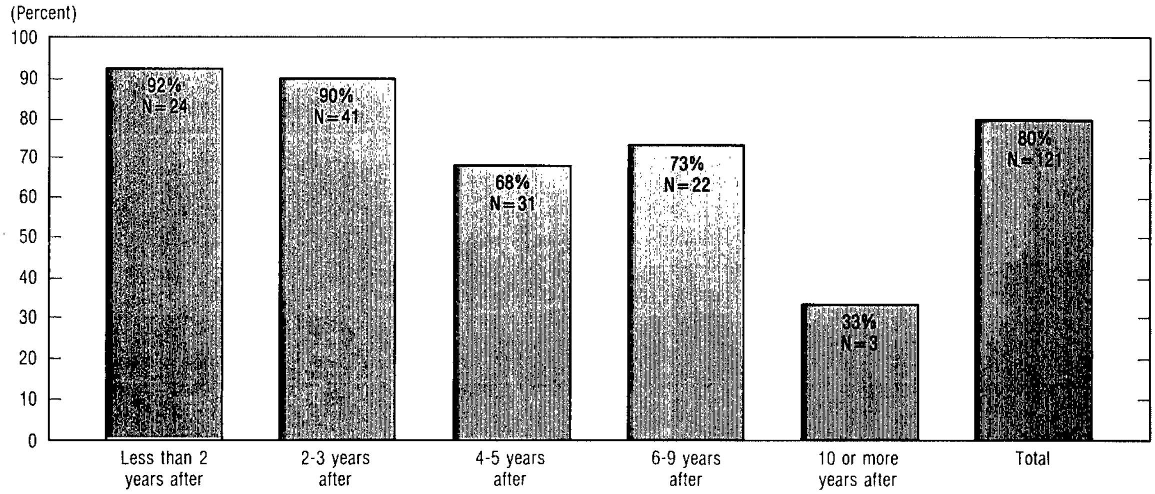
[128] Mansfield, "International Technology and Trade Flows."

[129] Ibid.; *Impact of Multinational Enterprises on National Scientific and Technical Capacities* (Paris: OECD, 1977).

[130] Vernon and Davidson, pp. 62-64.

Figure 1-15

U.S. transfers of innovations to manufacturing subsidiaries in 1966-75 as a percent of total transfers[1]



[1]Percent of actual number of times 57 innovations were introduced abroad by 32 U.S.-based multinational enterprises.

NOTE: Based on a sample of 221 innovations introduced abroad by 32 U.S.-based multinational enterprises during the period 1945-75.

REFERENCE: Appedix table 1-27.

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terms of time and resources required and level of efficiency achieved. The quality characteristics of the transferred technology is determined by its age and exclusivity, ease of local absorption, suitability of production methods to local scale requirements, and general production environments. The effectiveness and efficiency of the transfer system are functions of the amount and complexity of the technology transferred; the technological gap between the supplier and recipient (including transfer skills of the former and adaptive capabilities of the latter) as well as the mode of transfer. Table 1-13 outlines some of the factors that influence the price of the transferred technology as well as its usefulness to the recipient.

Another important aspect of technology transfer is the benefit to consumers. Despite serious problems of domestic economic adjustments, using foreign technology or goods may provide less expensive consumer or intermediate goods. Electronic products and pharmaceuticals are examples of product areas in which consumers have benefited from foreign technological progress.[131] Japan has demonstrated the benefits of absorbing and using the technical contributions of other nations.

Table 1-13. Factors influencing the price of a transferred technology and its utility to the recipient

Supplier Enterprise:

- U—Transfer capabilities
- UP—Potential commercial value of technology
- P—Alternative sources of analagous technology
- P—Proprietary technology (patents, trademarks)
- UP—Unique know-how (firm-specific or system specific)

Technology Transferred:

- UP—Sophistication of product
- UP—Quantum and complexity of transfer package
- UP—Age (in product-cycle)

Mode of Transfer:

- U—Joint venture, license, or management service contract
- U—Sustained enterprise-to-enterprise relation or limited technical support services

Recipient Enterprise:

- U—Technical absorptive capabilities of firm and production environment
- P—Alternative sources of competitive technology
- P—Negotiating power (financial resources experience, government support)

U = factor primarily influencing utility.
P = factor primarily influencing price.

SOURCE: Jack Baranson, "Critique of International Technology Transfer Indicators," *Indicators of International Technology Transfer and Trade Flows*. National Science Foundation, 1981.

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[131] Rosenberg.

International Technology Flow Summary

While there are limitations to many of the indicators available to analyze international technology and trade flows, the trends do reinforce one another and thus provide a greater degree of confidence in the findings. The United States is a net exporter of technological products and information through a variety of channels, including licensing agreements, foreign direct investment, and trade, and this outward flow of technology appears to be increasing. The United States still maintains a strong competitive advantage but some evidence of a decline in its position can be seen in its share of the world trade in R&D-intensive products.

In licensing agreements, the United States sells nine times more technology than it buys. The U.S. balance of payments in royalties and fees increased 257 percent from 1967 to 1978, reaching a level of $4.8 billion. Direct investment abroad by U.S. firms has been growing, and there is evidence that firms generally favor the subsidiary channel, particularly when introducing new and/or exceptionally profitable innovations. There also is some evidence that there has been an increase in the rate of transfer abroad of new product production by U.S. subsidiaries. Firms considered to be R&D-intensive are moving the production of their new products abroad at a faster rate than firms with lower R&D intensities. The amount of R&D performed abroad by U.S. subsidiaries also increased, rising 88 percent from 1975 to 1979, to a level of $2.7 billion in 1979. This is equal to 11 percent of U.S. domestic industry's own R&D funds.

The U.S. positive balance of trade in R&D-intensive manufactured products is an indicator of the competitiveness of U.S. technology and technological earning power. This trade balance has been positive over the past two decades and has increased dramatically since 1972, to $39.3 billion in 1979. While the United States still has a strong competitive advantage in R&D-intensive products and technical information, there is evidence of some erosion in that position relative to West Germany and Japan, each of whom has penetrated the U.S. market in these products. The trade deficit with Japan in R&D-intensive manufacturing products has increased dramatically—over 900 percent during 1974-78—reaching a level of $5.7 billion. This negative trade balance has improved somewhat and in 1979 was -$4.3 billion. Further evidence of some deterioration in the U.S. competitive position in technological products can be found in the declining U.S. share of world exports of R&D-intensive products. While the U.S. market share is still highest, it dropped from 31 percent in 1962 to 21 percent in 1977. At the same time, Japan increased its market share from 5 percent to 14 percent. However, this drop in U.S. market share may partially be due to change in mode of transfer to production by foreign subsidiaries rather than exports.

At first glance, the transfer of technology abroad might appear to be associated with declines in U.S. market shares, but closer examination of the trade data provides little solid evidence to support this conclusion.[132] Most direct foreign investments occur in R&D-intensive industries (machinery and chemicals) and research indicates that increased exports are associated with this foreign investment. Exports are not the only form of technological earnings; licensing agreements and earnings from foreign direct investment should also be taken into consideration. There is evidence that the preferred mode of technology transfer, and therefore the source of technological earnings, is through U.S. subsidiaries abroad. Additionally, it is possible that U.S. innovations with a laborsaving orientation may not be as relevant to today's needs as they once were. Japanese and European capitalsaving and energysaving innovations may be more in demand. Finally, as shown in the first section of this chapter, other countries—especially Japan and West Germany—have been increasing their own scientific and technical capabilities.

INTERNATIONAL SCIENTIFIC COOPERATION

As is evident from the earlier sections of this chapter, there has been a great deal of growth of scientific and technical capabilities in the countries which have traditionally spent large amounts on R&D and represent the majority of world investment in R&D. Not only have these countries expanded their S&T capabilities, but a study of 50 countries over a 10-year period (1967-76) showed that during this period there was above average growth in the number of publishing scientists (corrected for the size of each nation's scientific community) in countries such as Spain, South Africa, New Zealand, Brazil, Nigeria, and Iran.[133]

The perceived technological gap between the

[132] Okubo.

[133] Eugene G. Kovach, "Country Trends in Scientific Productivity" *Who Is Publishing in Science* (Philadelphia, Pa.: Institute for Scienctific Information, 1978), pp. 33-40. This analysis was based on the number of scientists publishing in journals accessed by WIPIS *(Who Is Publishing in Science).* The increase in coverage of WIPIS from about 3,500 journals in 1967 to about 5,000 in 1978 is responsible for a part of the growth, but it is undeniable that the number of publishing S/E's has increased in these countries.

United States and Europe and Japan, so often spoken of during the 1960's, has greatly diminished. There is increased technological and economic competition but there are also expanded opportunities for scientific cooperation.[134] International scientific cooperation contributes to the advancement of world science, diffusion of knowledge, improved relations between countries, and greater human understanding. The direct exchange of methods and experimental results (e.g., through international meetings and the conduct of research abroad) can often act as a synergistic impetus to domestic scientific research by providing fresh outlooks and new perspectives.

Despite these advantages, there are possible drawbacks to international scientific cooperation. Besides the possibility of enhancing the technological competitiveness of other nations, there are often operational limitations, including security problems, time delays due to increased organizational complexities, and decreased ability to make independent decisions about the direction and goals of the research.

International cooperative science includes activities such as joint research projects and seminars/workshops, exchange of scientists, joint commissions for scientific and technical cooperation, and participation in international scientific organizations. This section presents indicators of international scientific cooperative activities in which the United States is involved.

There are various reasons why governments engage in and support international scientific cooperation. The exchange of ideas can be a fruitful stimulus to research.[135] Often, a particular scientific phenomenon or problem which is of interest to scientists of many countries is the impetus for international cooperation. An example of this type of project is the U.S.-India Agreement on the Monsoon Experiment (MONEX), in which research will expand our understanding of monsoons and perhaps improve the capability to forecast monsoon rains. Some phenomena are global in nature and require the concerted effort of many nations such as the International Magnetospheric Study. Sometimes international cooperation centers on a unique facility such as CERN (the European Council for Nuclear Research), the *Glomar Challenger*, the U.S. deep sea drilling ship, or the National Astronomy Centers. The output of these types of joint projects can be seen in the following section on cooperative literature, which shows that international coauthorship is highest in the fields of physics and earth and space sciences.[136]

International cooperation can provide foreign solutions to domestic problems. For instance, under a technology exchange grant a French solid waste districting and routing system was adopted in several U.S. cities. S&T cooperation with our neighbors can help us attack problems that transcend national borders such as pollution, pursue common interests, and cement good relations. In 1972, the first agreement on science and technology cooperation between Mexico and the United States was signed and has since been strengthened. Under this agreement, several projects in geology, geochemistry, geochronology, and geological exploration have led to the development of better prospecting techniques for copper exploration in both countries.[137]

Improved international relations is usually a by-product of international scientific cooperation,[138] but sometimes it can be a primary goal as well. The normalization of relations with the People's Republic of China (P.R.C.) has been assisted by the promise and fulfillment of scientific and technical cooperation. In January 1979, the United States concluded an agreement on science and technology with China and a protocol was signed in December 1980 for cooperation in a broad variety of S&T fields. Emphasis this first year will be placed on archeology, astronomy, systems analysis natural products chemistry, material science, and linguistics.[139]

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[134] *Science and Technology in the New Socio-Economic Context* pp. 19-21; *Science and Technology Promises and Dangers in the Eighties*, President's Commission for a National Agenda for the Eighties, 1980, pp. 39-47.

[135] The value of personal contact with scientists of other countries has been documented in interviews with approximately 50 senior scientists, administrators, and government officials in visits to 12 universities, 5 research institutes, and a number of foundations, international research organizations, and Government bureaus in Great Britain, Switzerland, West Germany, and France. See Dorothy S. Zinberg, "Planning for Contraction: Changing Trends in Travel Patterns of American and European Scientists," *New U.S. Initiatives in International Science and Technology*, Denver, Colo.: Denver Research Institute, University of Denver, 1977), pp. 193-213.

[136] See figure 1-18.

[137] Harvey Averch, "Statement before the Subcommittee on Finance and International Trade," Finance Committee, U.S. Senate, October 1, 1979.

[138] For an extensive discussion of how science and technology create both opportunities and problems in the achievement of goals, see *Science Technology and American Diplomacy*, Committee on International Relations, U.S. House of Representatives, 1977; *Science Technology and American Diplomacy, 1980*, submitted to the Committee on Foreign Affairs and the Committee on Science and Technology, U.S. House of Representatives, 96th Congress, August 1980.

[139] "The Protocol of the National Science Foundation of the United States of America and the Chinese Academy of Sciences and the Chinese Academy of Social Sciences of the People's Republic of China on Cooperation in the Basic Sciences," December 10, 1980.

Another example of projects of interest to both countries is the U.S.-P.R.C. Cooperative Earthquake Research Program which will encompass joint research activities on fundamental seismology, earthquake prediction, earthquake engineering, urban planning and design, and mitigation of societal hazards.

Although these are examples of the many ongoing cooperative programs, there are other areas in which U.S. scientists and engineers could gain from collaboration with foreign scientists. Appendix table 1-28 identifies examples of possible areas of increased scientific cooperation with Western Europe. These are areas in which Western European efforts are thought to be at a level of excellence comparable to that of the United States, or in which achievements were linked to the availability of unusual instrumentation or facilities.[140]

International Cooperation in Academia

International cooperation has been a strong tradition in U.S. universities and colleges. Their involvement has included such activities as the education of foreign students here and abroad, cooperative R&D programs, assistance in the establishment and improvement of educational and research capabilities, and development of curriculums in problem areas of particular concern to developing countries.[141] Such cooperation has gained in importance as developing countries have increased demands for advanced technologies. There has been a growing awareness of the importance of assisting developing countries to build up their scientific capabilities[142] and increasing nations' indigenous capabilities to deal with such problems as world hunger. The domestic demographic and economic trends leading toward lower U.S. student populations entering colleges and universities also have made increasing foreign enrollments more feasible and desirable from the universities' viewpoint. However, some concern is now being expressed over the increasing percentages of foreign students who are studying and remaining in the United States.

The number of foreign students enrolled in U.S. universities and colleges during the academic year 1979-80 rose to a record level of 286,340—more than eight times the number of foreign students in 1954-55. Nevertheless, their total number represents a small fraction of all students in U.S. higher education—about 1.5 percent for most of the past 25 years, and about 2.4 percent in 1979-80. Over half of the foreign students (58 percent) were from Asia; 15 percent were from Latin America; and 13 percent were from Africa. Since 1954-55, the number of students from Asia and Africa has increased while the number from Latin America has decreased. The student population from Europe has also declined over the years to its present low of 8 percent.[143]

Over the past two decades, the proportion of U.S.

[140] These fields were identified by a survey of National Science Foundation program officers (unpublished).

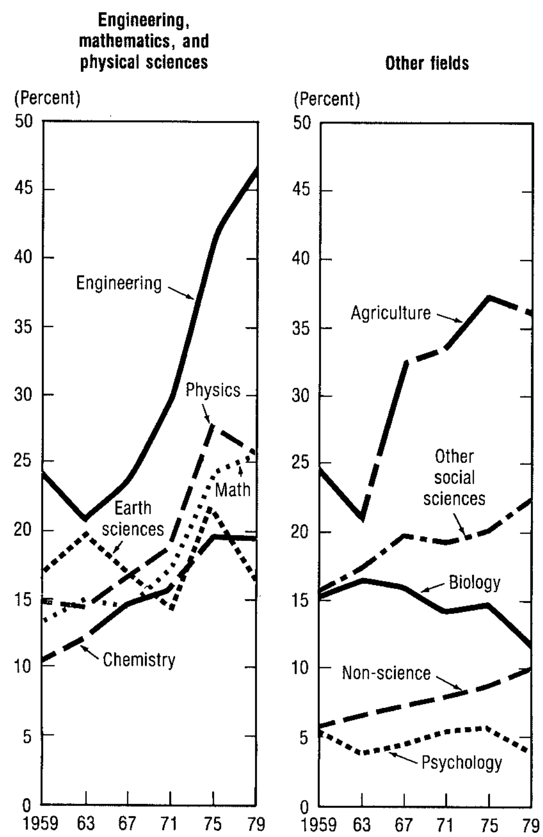
[141] For a complete review of U.S. academic involvement in developing countries, including possible future directions, see Robert P. Morgan, *The Role of U.S. Universities in Science and Technology for Development: Mechanism and Policy Options* (St. Louis, Mo.: Washington University, 1978).

[142] *U.S. National Paper prepared for the 1979 UN Conference on Science and Technology for Development: A Contribution to the 1979 UN Conference* (Washington, D.C.: National Research Council, 1978).

[143] *Open Doors: 1979/80* (Washington, D.C.: Institute of International Education, 1981), pp. 1-5. Problems were encountered in the early 1970's with response rates, but the data-collection system was greatly improved in 1974/75.

Figure 1-16

Doctoral degrees awarded to foreign students as a percent of all doctoral degrees from U.S. universities by field



REFERENCE: Appendix table 1-29.

Science Indicators—1980

doctoral degrees awarded to foreign students in scientific and technical fields has risen from 15 percent in 1959 to 21 percent in 1979. Figure 1-16 shows the proportions of foreign doctoral degrees conferred by field. In 1979, nearly half of all engineering doctorate recipients were foreign students (47 percent). Other fields in which a high share of doctoral degrees were awarded to foreign students were agriculture and forestry (35 percent), mathematical sciences (26 percent), and physics and astronomy (26 percent). These fields have all experienced high growth in foreign concentration of doctoral degrees awarded since the mid-1960's. However, the actual number of foreign doctorate recipients has declined since the mid-1970's.[144] Even so, the foreign share of doctoral degrees increased because the total number of doctorate recipients declined during the seventies in each of these fields except agriculture and forestry.[145]

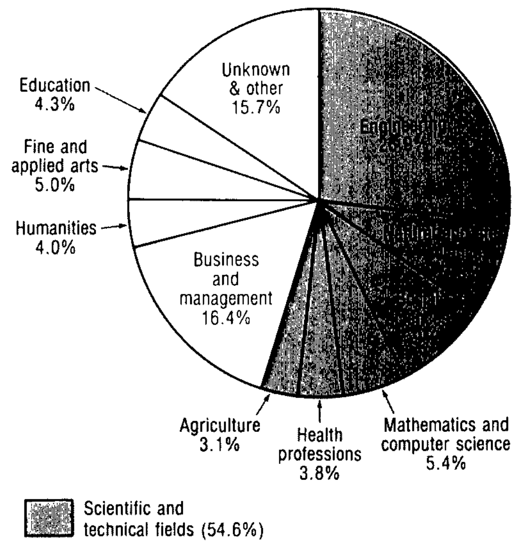
Foreign students with permanent visas are immigrants who become part of the domestic labor supply of doctoral scientists and engineers. In 1979, these students represented only 6 percent of the total number of recipients of U.S. doctoral degrees in science and engineering. Temporary-resident foreign citizens account for the majority of foreign recipients of U.S. doctorates in science and engineering. They are choosing to remain in the United States in increasing numbers and have become an important factor in the U.S. domestic labor supply in some fields—especially engineering and mathematical sciences.[146]

As figure 1-17 demonstrates, about 55 percent of all foreign students in the United States are studying in scientific and technical fields; almost half of these S&T students are engaged in engineering programs. Substantial increases in the numbers of students have occurred in all fields in the past 25 years, but mathematics and computer sciences have grown very rapidly, from only 436 foreign students in 1954-55, to about 15,400 in 1979-80. Currently there are over 10 times as many foreign engineering students in the United States as there were in the mid-1950's. The proportion of foreign students studying in the natural and life sciences has been declining since 1964-65, and is at its lowest point (8 percent) in 25 years,[147] although the actual number of students has risen. Table 1-14 demonstrates that foreign scientists and engineers also represent a large portion of the postdoctoral population in the United States; fully a third of all postdoctoral students working in science and engineering fields are from foreign countries. More than 60 percent of all engineering postdoctoral students training in the United States are foreign, as well as almost half of all postdoctoral physical scientists.

From 1977 to 1979, the total number of postdoctoral students in U.S. doctorate-granting insti-

Figure 1-17

Percentage distribution of foreign students by major fields of study: 1979/80



REFERENCE: Appendix table 1-30. Science Indicators—1980

Table 1-14. Foreign postdoctoral students in U.S. doctorate-granting institutions: 1979

[Percent]

Fields of science	Total	Foreign	Percent foreign
All fields	18,589	6,075	33
Engineering	1,073	663	62
Physical sciences	4,028	1,992	49
Environmental sciences[1]	329	112	34
Mathematical sciences	203	94	46
Life sciences	12,089	3,079	25
Psychology	456	34	7
Social sciences	411	101	25

[1]Includes earth sciences, oceanography, and atmospheric sciences.

REFERENCE: Appendix table 1-31. Science Indicators — 1980

[144]National Science Foundation, unpublished data.

[145]*Summary Report 1979 Doctorate Recipients From United States Universities* (Washington, D.C.: Commission on Human Resources, National Research Council, 1980), pp. 4-12.

[146]National Science Foundation, unpublished data.

[147]See appendix table 1-30.

tutions declined 6 percent (see appendix table 1-31). Most of this decline was accounted for by U.S. citizens; the number of foreign postdoctoral students decreased only 2 percent. Over this 2-year period, the foreign percentage of postdoctoral students rose from 53 percent to 62 percent in engineering; from 41 percent to 49 percent in the physical sciences; and from 37 percent to 46 percent in mathematics.

While foreign postdoctoral study in the United States has been increasing, U.S. doctoral graduates are going abroad less frequently for postdoctoral study. Both in number and percent of total doctorates, the peak year for U.S. doctorate recipients with plans to continue their training abroad was 1971. At that time, 430 (1.5 percent) of all U.S. doctorates had firm commitments for study abroad, but by 1979 the number had declined by almost half of 236 (0.9 percent).[148] The fact that the influx of S/E postdoctoral students into the United States is much greater than the outflow of U.S. postdoctoral candidates abroad may reflect the value of U.S. scientific training. Graduate training abroad is recognized as an important experience and the decline in the number of U.S. postdoctoral students going abroad comes at a time when they could benefit from improved scientific facilities in Western Europe. U.S. graduates may be foregoing foreign postdoctoral experience for a variety of reasons, including tenure or employment concerns or cost of living differences.[149]

In addition to training foreign students here in the United States, U.S. universities have contributed to the development of foreign universities and research activities. A 1978 survey of doctorate-granting colleges and universities found that of 203 responding institutions, almost two-thirds had at least some science and engineering faculty members who had taught abroad during the previous 2 years; three-fourths of the respondent institutions had faculty who collaborated on research with foreign counterparts; and three-fourths had faculty who traveled abroad for research purposes.[150] Data from another survey showed that of those faculty members reporting collaborative scientific and engineering activities with developing countries, 24 percent taught abroad, 46 percent were engaged in collaborative research, and 30 percent were involved in consultation and scientific cooperation.[151] These activities not only assist foreign research activities, but often broaden and enrich the experience of the U.S. scientific and technical community.

In short, the U.S. role in educating and training foreign students and assistance in the development of foreign universities has been one of this Nation's largest contributions to development of world scientific and technological capabilities and has led to the expansion and enhancement of the human resource capabilities of foreign countries.

Table 1-15. Participation in international scientific congresses

Year	Number of congresses	Total participants	U.S. participants	Non-U.S. participants
Total	285	358,667	80,983	277,684
1960-1962	23	33,082	9,033	24,049
1963-1965	28	37,964	10,012	27,952
1966-1968	42	59,748	12,297	47,451
1969-1971	38	55,711	12,956	42,755
1972-1974	73	73,819	18,630	55,189
1975-1977	52	59,658	12,767	46,891
1978-1979[1]	29	38,685	5,288	33,397

[1]Only represents a two-year period.

SOURCE: National Academy of Sciences, unpublished data.

Science Indicators—1980

International Scientific Congresses

International conferences and symposia provide a ready forum in which scientists often can communicate their findings more rapidly than by publishing them in a journal. At the same time, they are able to receive immediate feedback and ideas from their colleagues. The informal exchange of ideas so characteristic of such meetings can lead to modifications of research, collaborative efforts, and elimination of duplicate work. A recent survey of U.S. university S/E department heads found that senior faculty are more likely to attend international meetings than are junior faculty. The two predominant benefits to be derived from attending such meetings were viewed as first, more complete and timely acquisition of scientific and technical information than is otherwise possible, and second, stimulating innovation and new lines of investigation for faculty members.[152] Table 1-15 shows the

[148] *Summary Report 1979 Doctorate Recipients From United States Universities*, pp. 12-15.

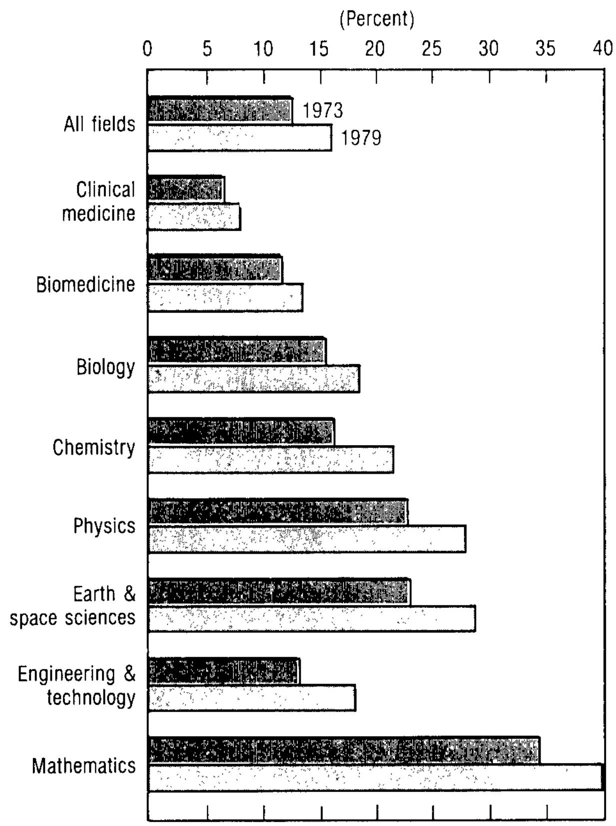
[149] "Expanded Scientific Cooperation with Western Europe," NSF Advisory Council, 1978, pp. 12-14.

[150] Irene L. Gomberg and Frank J. Atelsek, *International Scientific Activities at Selected Universities 1975-76 and 1976-77* (Washington, D.C.: American Council on Education, 1978), pp. 10-11.

[151] Frank J. Atelsek and Irene L. Gomberg, *Scientific and Technical Cooperation with Developing Countries 1977-78* (Washington, D.C.: American Council on Education, 1978), p. 12.

[152] Frank J. Atelsek and Irene L. Gomberg, *An Analysis of Travel by Academic Scientists and Engineers to International Scientific Meetings in 1979-80* (Washington, D.C.: American Council on Education, 1981), pp. 4-6, 13-14.

Figure 1-18
Index¹ of international cooperative research by field



¹Obtained by dividing the number of all scientific and technical articles which were written by scientists and engineers from more than one country by the total number of articles jointly written by S/E's from different organizations regardless of the country involved.

NOTE: Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

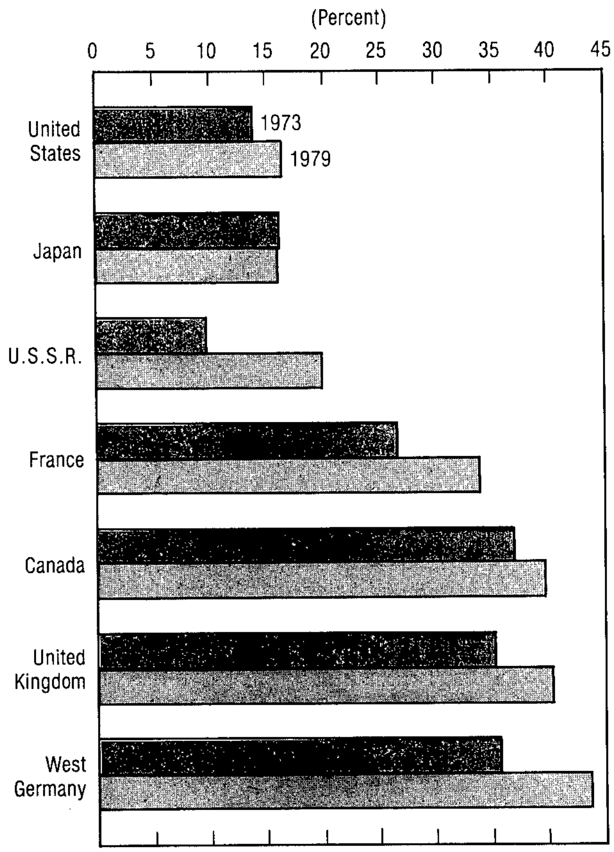
REFERENCE: Appendix table 1-32. Science Indicators—1980

participation in international congresses of those organizations constituting the International Council of Scientific Unions. Wide fluctuations in attendance occur from year to year due to such factors as the number and locations of meetings to be held. Many congresses meet only every 3 or 4 years and the convergence of these cycles can create peaks in participation patterns. Foreign participation in these meetings grew rapidly in the 1960's, while U.S. participation increased at a more moderate pace. As a result, the U.S. share of total participation has declined from about 27 percent in the first few years of the sixties, to an average of about 23 percent in the early and mid-seventies, and then down to 14 percent during 1978-79. Since the mid-1970's, there has been a decline of both U.S. and foreign total participation. Increasing travel costs due to the rising cost of fuel and decreasing availability of travel funds may be factors in this decrease.

Cooperation in S&T Literature

Evidence of international scientific cooperation can be seen when scientists or engineers of different countries jointly author a publication. While coauthorship is fairly common among authors of the same organization, it is not as common among

Figure 1-19
Index[1] of international cooperative research by country



[1]Obtained by dividing the number of all articles which were written by scientists and engineers from more than one country by the total number of articles jointly written by S/E's from different organizations regardless of the country involved.

NOTE: Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

REFERENCE: Appendix table 1-33.

Science Indicators—1980

authors of different institutions[153] and is even more rare among scientists of different countries. International collaboration in research is often the product of regional or international scientific centers or the outcome of bilateral scientific agreements or joint national projects. Graduate study abroad and attendance at international scientific meetings can also facilitate and encourage joint authorship of scientific papers.

Figure 1-18 provides an index of international cooperative research for the 1973-79 period. It shows that international cooperation, expressed in terms of joint authorship by authors from different countries, has increased slightly in all fields combined—from 13 percent of all multiple-authored publications in 1973 to 16 percent in 1979. By this measure, the fields which are most internationally cooperative are mathematics, the earth and space sciences, and physics. The greatest increases in international cooperative authorship over this period were in the fields of engineering and chemistry.

Given the various benefits of international scientific cooperation, including conservation of re-

[153]See the Resources for Research and Development and Industrial R&D and Technological Progress chapters for discussions of cooperative research among scientists and engineers of different sectors in the United States.

search time and costs and a greater awareness of foreign research, is the United States engaging in as much cooperative research as other nations? Figure 1-19 sheds light on this question by providing an index of international cooperative research based on percentages of jointly-authored articles by scientists and engineers from different countries.[154] West Germany, the United Kingdom, and Canada have the highest levels of cooperative authorship; over 40 percent of all the articles which were jointly authored between organizations were internationally cooperative in nature. The United States and Japan have the lowest ratios of international cooperative authorship—less than half that of the first three countries.

The largest increase in international cooperation based on this index occurred in the Soviet Union, over half of which represented collaboration with East Germany (24 percent) and the rest of Eastern Europe (29 percent).[155] Perhaps because of former programs supporting U.S./U.S.S.R. scientific and technical cooperation, one-fifth of the increase through 1979 was with the United States, followed by a 6-percent increase of Soviet coauthorship with West Germany.

West Germany experienced the next greatest increase in international cooperative research from 1973 to 1979—one-third accounted for by the United States and 16 percent by France. The next-largest increase occurred in France, with the United States participating in 26 percent of the increase and West Germany in 18 percent.

The level of U.S. cooperative research with other countries does not appear to have increased greatly over the 1973-79 period (up 2.6 percent). The United States has a diffuse pattern of internationally cooperative research while many other major nations have concentrated their cooperation on collaborative efforts with only a few countries. The percentage of new internationally coauthored articles accounted for by a country's two most active collaborating countries can be a measure of this concentration, as shown below:

United States	29 percent
France	44 percent
West Germany	50 percent
Soviet Union	53 percent

This difference may suggest that a higher value is placed by a larger number of countries on working with U.S. scientists and engineers, or that the

[154] Comparisons are made here with the seven countries which produce the greatest proportion of the world's scientific and technical literature: the United States, the United Kingdom, the Soviet Union, West Germany, Japan, France, and Canada. These seven countries together represented over 70 percent of the world's influential scientific literature in 1979.

[155] Country-by-country data in this section are based on unpublished data from Computer Horizons, Inc., Cherry Hill, N.J., 1980.

Table 1-16. Distribution index of articles in U. S. and foreign journals[1] by fields

Field[2]	U. S. articles in non-U. S. journals		Non-U. S. articles in U. S. journals		Balance[3]	
	1973	1979	1973	1979	1973	1979
All fields	19,157	20,060	28,425	36,353	9,268	16,293
Clinical medicine	4,695	5,268	6,794	8,898	2,099	3,630
Biomedicine	4,124	4,896	4,148	5,493	24	597
Biology	1,660	2,037	2,013	2,587	353	550
Chemistry	2,346	2,036	5,484	6,769	3,138	4,733
Physics	2,661	2,525	4,118	6,095	1,457	3,570
Earth and space sciences	1,200	1,179	1,284	1,251	84	72
Engineering and technology	1,382	1,351	3,723	4,241	2,341	2,890
Mathematics	1,089	768	861	1,019	−228	251

[1] Based on the articles, notes and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* Corporate Tapes of the Institute of Scientific Information. For the size of this data base, see Appendix table 1-12.

[2] See appendix table 1-13 for a description of the subfields included in these fields. Note that because psychology journals began to be removed from the *SCI* on 1978 for inclusion in the *Social Sciences Citation Index*, the "All fields" totals for all years exclude psychology articles.

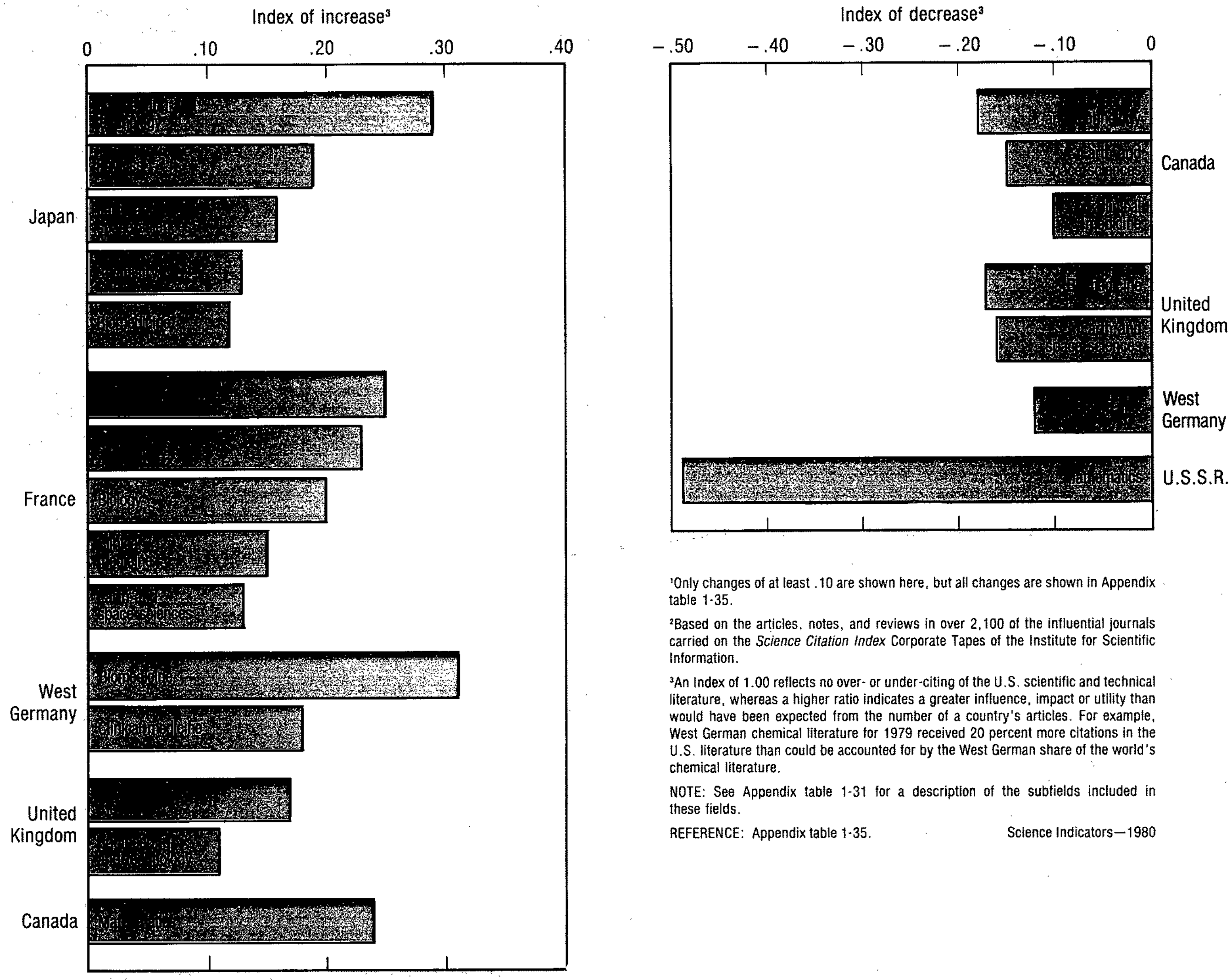
[3] When the balance is negative, it means that more U. S. scientific and technical articles are being published in journals abroad than foreign articles published in U. S. journals. When the balance is positive, the United States is publishing more foreign articles than U. S. authors are published abroad.

REFERENCE: Appendix table 1-34.

Science Indicators — 1980

Figure 1-20

Selected changes[1] in U.S. utilization of foreign scientific and technical literature[2]: 1973-1979



[1]Only changes of at least .10 are shown here, but all changes are shown in Appendix table 1-35.

[2]Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[3]An Index of 1.00 reflects no over- or under-citing of the U.S. scientific and technical literature, whereas a higher ratio indicates a greater influence, impact or utility than would have been expected from the number of a country's articles. For example, West German chemical literature for 1979 received 20 percent more citations in the U.S. literature than could be accounted for by the West German share of the world's chemical literature.

NOTE: See Appendix table 1-31 for a description of the subfields included in these fields.

REFERENCE: Appendix table 1-35.

Science Indicators—1980

combination of a relatively large volume of U.S. papers occurs in those fields which are by their nature more eligible for international cooperative research.

Another form of international scientific exchange is publication of technical articles in another country's journals. This activity has a double benefit: a nation which publishes the articles of foreign scientists and engineers in its domestic journals provides a dissemination service for world science and provides its own scientists and engineers with a more rapid access to the latest foreign research findings. The extent to which a nation publishes more foreign scientific findings than its own researchers publish abroad is an indication of its capacity to promulgate the world's scientific literature as well as of its interest in foreign research. In the United States, the largest such balances are in the fields of chemistry, clinical medicine, physics, engineering, and technology (see table 1-16). In terms of absolute numbers of articles, U.S. journals publish the greatest number of foreign articles in the above four fields. However, U.S. biomedical scientists also publish a great deal in foreign journals, thereby leaving the balance relatively low. In fact, U.S. scientists publish more articles abroad in the two fields of clinical medicine and biomedicine than in the other fields combined.

U.S. Utilization of Foreign Science

Much can be learned from the findings of other nations' scientists. As other countries increase their scientific and technical capabilities, it becomes more important and more beneficial to the United States to be aware of and use foreign scientific results. Figure 1-20 shows that in many fields U.S. scientists are doing just that: in particular, from 1973 to 1979, they have increased their use or citation of the scientific literature of Japan and France. Growth in U.S. use occurred in five of the eight fields for each of these two countries. For Japan, the largest increases were in engineering and technology and in physics, and for France, in chemistry, biomedicine, and biology. There was also a large growth in the use of West German biomedical findings, which accompanied a decrease in the use of U.K. and U.S. output in this field.

Utilization of Soviet mathematics literature dropped dramatically over the period. U.S. mathematicians apparently shifted to a higher use of both Canadian and U.S. mathematics results. However, the use of Canadian scientific literature declined in the fields of engineering and technology, earth and space sciences, and clinical medicine.

OVERVIEW

The United States still spends more on research and development and has more scientists and engineers engaged in R&D than any other country except the Soviet Union. However, other nations, particularly Japan and West Germany, have greatly increased their technological capabilities. Additionally, a substantial portion of the U.S. population may not have as solid a scientific and technical background as their counterparts in Japan, West Germany, and the Soviet Union because these countries have stressed science and mathematics literacy in their secondary schools to a greater degree and for a larger cross section of students. However, at higher education levels, U.S. graduates in S&T fields are believed to receive more flexible and broad-based theoretical education than their Soviet counterparts.

There are differences between the United States and other countries in the allocation of R&D funds. In Japan and West Germany, industry provides a majority of the funds and Government funds are highly concentrated in areas directly related to economic growth. On the other hand, in the United States, more than half of the R&D funds are from public sources and over half of these Government funds are oriented toward defense and space objectives. These differences in R&D orientation may have had an impact on national patterns of economic growth. Over the past decade, the United States has experienced slower growth rates in manufacturing productivity than most industrialized countries, while Japan and West Germany have enjoyed some of the highest productivity growth rates. Capital expenditures often embody new technologies and R&D advances, and low rates of capital investment are seen as a factor in the U.S. productivity slowdown. Since 1960, capital investment rates (capital investment as a percent of output) in both manufacturing and the total economy, have been lower in the United States than in all other major industrialized countries.

Domestic and foreign patenting activity by U.S. inventors has declined since 1971. In contrast, foreign patenting activity in the United States has increased—largely reflecting a rise in the number of patents granted to Japanese inventors. West Germany and Japan account for over half of all foreign-origin patents in the United States. During the 1970's, while many other countries were experiencing declines in their domestic patenting, Japan and West Germany appeared to be increasing their inventive activity as the number of domestic patents granted to their nationals increased substantially. The patenting activity of these two

countries in the United States is related to commercial interest in the U.S. market as well as increased inventive activity; this market interest is borne out by the negative trade balances the United States has with Japan and West Germany in R&D-intensive manufactured products.

The United States continues to transfer large amounts of technology abroad through a variety of channels including foreign direct investment, licensing agreements, and exports of R&D-intensive manufactured products.

While the United States still has a strong competitive advantage in R&D-intensive products and technical information, there is evidence of some erosion in that position. The U.S. share of world exports of R&D-intensive products has decreased and the United States has a trade deficit in such products with Japan and West Germany.

There have been changes in the world market demands for technological innovations. U.S. industries, like their European and Japanese counterparts, now confront markets that place a greater relative importance on the conservation of energy, raw materials, and capital. This is a new emphasis for American entrepreneurs, while the Europeans and Japanese are more experienced at finding ways to save on these factors. The Americans can no longer count on having much of an innovation lead over their competitors; international competition through innovation is likely to become stiffer, and technological leads shorter.

The United States has played an important role in the training of foreign S/E students both here and abroad. As foreign scientific and technical capabilities improve, there may be greater economic and technical competition, but there is also more opportunity to gain from international scientific cooperation. At a time of restrained national budgets, there are many advantages to strengthening our joint scientific research efforts with other nations and increasing our awareness and utilization of foreign R&D. There are indications that U.S. scientists are increasing their use of foreign science in a number of fields.

Chapter 2
Resources for Research and Development

Resources for Research and Development

INDICATOR HIGHLIGHTS

- After a period of no growth in the first half of the decade, 1976 to 1979 constant-dollar R&D expenditures advanced at an average annual rate of 4 percent, and estimates for 1980 and 1981 indicate that R&D spending will continue to grow in constant-dollar terms, but perhaps not so rapidly as in the earlier period. High inflation rates of recent years have had a major impact on the amount of funding available for scientific and technological activity. Measured in current dollars, national R&D spending in 1981 will amount to about $69 billion. (See pp. 51-52.)
- The ratio of R&D expenditures to GNP was at its highest point in 1964 when it reached 2.96 percent. Since then the ratio has fallen, dropping to a low of 2.23 percent in 1978. Estimates indicate that by 1981 it will grow to 2.37 percent. See p. 52.)
- Of the three components of R&D, basic research has had the most dramatic funding growth in recent years, followed by development, and then applied research. After adjusting for the effects of inflation, basic research spending grew at an average annual rate of 5.6 percent from 1976 to 1979, while development and applied research had average annual growth rates of 4.2 percent and 3.2 percent, respectively. Estimates for 1979 to 1981 indicate that spending in each of these areas will continue to grow, but not so rapidly as in the earlier period. The Federal Government has singled out basic research as needing continued support, and this interest is primarily responsible for the increases that have been realized. Applied research has also benefited from increased Federal funding but has been affected much more by very substantial growth in support from industrial sources. (See pp. 58-60.)
- R&D employment for scientists and engineers has risen steadily after a period of decline from 1969 to 1972. In 1980, an estimated 659,000 scientists and engineers were employed in R&D on a full-time-equivalent basis—more than 70 percent of whom were working in the industrial sector. (See p. 56.)
- Constant-dollar R&D funding by both Federal and industrial sources has grown in recent years, advancing at average annual rates of 2.8 and 5.6 percent, respectively, between 1976 and 1979. Estimates for 1980 and 1981 indicate that funding by these sources will tend to level off or show only slight increases in those years. (See pp. 52-53.)
- Federal R&D spending can be divided into three major categories: national defense, space, and civilian. The proportion of funds for each has remained relatively constant in recent years, with defense representing about half of the total, and space and civilian R&D holding 14 and 34 percent, respectively. In civilian R&D, health receives the largest fraction of funding, followed by energy. (See pp. 60-64.)
- Between 1976 and 1981, current-dollar R&D obligations in each of the major Federal functional areas have grown markedly, with defense and civilian functions advancing 77 and 68 percent respectively above the 1976 level, and space growing by 58 percent. Even more dramatic, however, is the recent increase in defense R&D obligations. Between 1980 and 1981, defense R&D grew by 23 percent, compared with increases of 7 percent for space R&D and 1 percent for civilian R&D. When these figures are adjusted for inflation, defense R&D obligations grew about 13 percent, while space and civilian obligations declined somewhat. (See pp. 60-64.)
- Industry is the largest of the R&D-performing sectors, accounting for about 71 percent of all R&D spending. Between 1976 and 1979, constant-dollar expenditures in this sector advanced at an average annual rate of about 4 percent and are expected to continue to grow at about the same rate through 1981. (See pp. 53-56.)
- Substantial support for R&D is provided through indirect support mechanisms that typically are not examined when studying overall R&D support data. Two of the most prominent indirect support mechanisms are Independent Research and Development (IR&D) and special tax treatment for R&D expenditures. Together, they accounted for more than $2 billion in 1979. (See pp. 67-70.)

The previous chapter of this report addressed the international character of R&D and discussed the United States in that context. This chapter deals with R&D resources within the United States as a means for understanding how resources for science and technology are provided in this country; as a way of assessing any changes in the way those resources have been made available; and as a method of tracking changes in the level of R&D activity over time.

The indicators presented here rely heavily on fiscal data to describe relative changes in the level of U.S. research and development activity. Such quantitative data provide a major basis for resource allocation decisions regarding support for various types of R&D activity, support in specific functional areas of R&D, and support provided by and to different economic sectors.

The pluralistic nature of support for scientific and technological activities makes resource allocation for R&D especially complex in the United States. R&D consists of diverse activities by many performers funded by a multitude of public and private interests. Consequently, the national resource allocation process, rather than representing an overall master plan, reflects decisions made at various Federal and private levels. Among the factors that exert substantial influence on the allocation of resources to R&D are economic conditions; pressure from the interests of citizens not directly involved with the research and development community; Federal policies toward science and technology; and social, economic, and technical opportunities.

In addition to the more traditional fiscal measures, other indirect, less quantifiable resources will be discussed in this chapter. Some of these resources include estimates of the extent to which special tax treatment for industrial R&D can affect R&D investment and a discussion of procedures used to reimburse corporations for R&D projects relevant to the Government's needs.

As in other chapters, dollars are used as a surrogate for R&D activity. The use of dollars as a measure is particularly sensitive to distortion caused by inflation; therefore, this analysis is in terms of constant dollars. In the absence of a specific R&D price deflator, the implicit price deflator for the Gross National Product (GNP) is used to convert current dollars to constant dollars; 1972 is used as the base or reference year. Since data on R&D funds are collected from performers who report expenditures according to both a fiscal and a calendar year, the quarterly GNP implicit price deflator is used to create a series of fiscal year as well as calendar year deflators. See appendix table 2-1 for the actual deflators used.[1]

NATIONAL RESOURCES FOR R&D

Information on the Nation's total spending for research and development is assembled from data on individual R&D fiscal decisions in diverse segments of the economy. This information reflects funding actions by the Congress, governmental agencies, private industries, universities and colleges, and nonprofit organizations. Thus, data on total expenditures can shed light on the collective behavior of the Nation's R&D sponsors and can point out major trends in support.

In terms of current dollars, national R&D spending has grown steadily between 1960 and 1979, and estimates show this growth will probably continue through 1981, reaching $69.1 billion (see figure 2-1). However, the high inflation rates which have prevailed in recent years have had a major impact on the buying power of funds available for R&D. Conversion to constant 1972 dollars reduces the estimated 1981 current-dollar level by about half. However, constant-dollar spending in recent years has been sufficient to produce growth, even with high inflation. Between 1976 and 1979, constant-dollar R&D expenditures grew at an average annual rate of approximately 4 percent. They are expected to grow at a slower rate between 1979 and 1981. Recent constant-dollar increases in R&D spending have resulted, to a large degree, from Federal initiatives in the late 1970's, combined with substantial recent increases in R&D expenditures by industrial sources. The functional areas of these R&D resources will be discussed more fully later in this chapter, but the Federal sector has tended to emphasize spending for defense, health, and energy, whereas the industrial sector has emphasized transportation, communications, and computers.[2]

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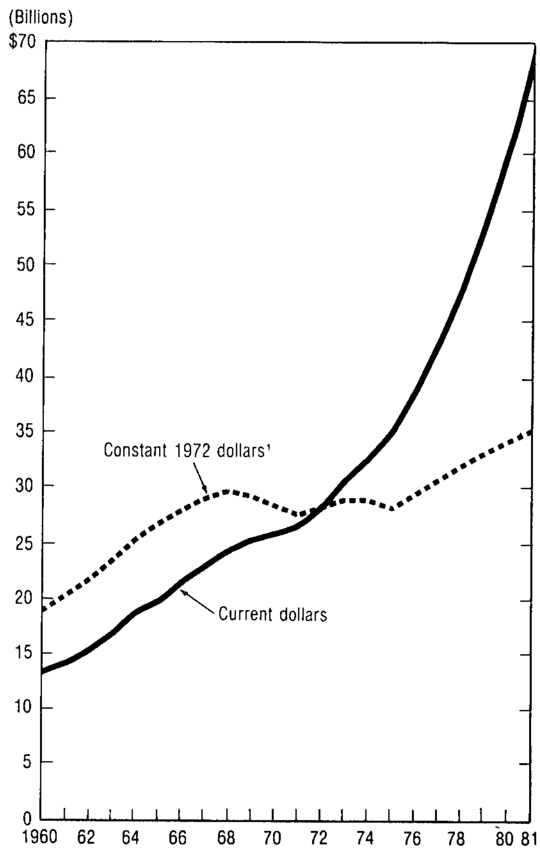
[1] Some studies indicate that use of the GNP implicit price deflator leads to an understatement of the effect of inflation on R&D dollars. A recent study of this issue, particularly as it applies to the industrial sector, is presented in Edwin Mansfield, "Research and Development, Productivity, and Inflation," *Science*, vol. 209 (September 5, 1980), pp. 1091-1093. Additional information concerning R&D price deflators can be obtained in D. Kent Halstead, *Higher Education Prices and Indexes, 1977 Supplement*, U.S. Department of Health, Education, and Welfare, National Institute of Education, 1977; and a paper produced by the Organisation for Economic Co-operation and Development entitled "Trends in Industrial R&D in Selected OECD Member Countries, 1967-1975," September 18, 1978.

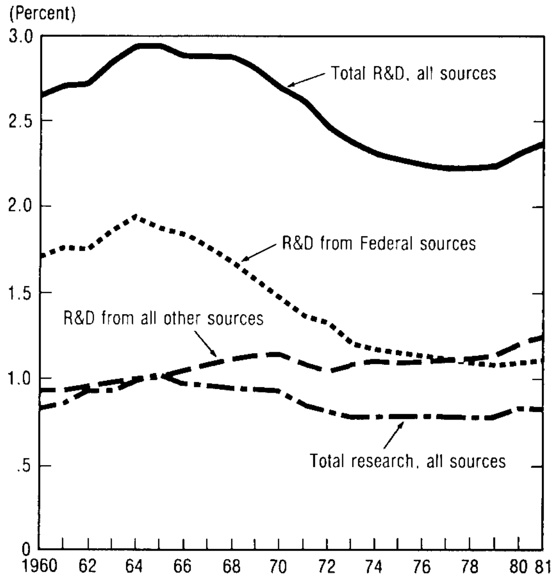
[2] See the chapter in this report entitled "Industrial Research and Technological Progress" for a more detailed discussion of industrial R&D spending.

Figure 2-1
National R&D expenditures



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Estimates are shown for 1979, 1980 and 1981.
REFERENCE: Appendix table 2-2. Science Indicators—1980

Figure 2-2
National R&D expenditures as a percent of GNP by source and research expenditure only, as a percent of GNP



NOTE: Estimates are shown for 1979, 1980 and 1981.
REFERENCE: Appendix table 2-3. Science Indicators—1980

R&D in the National Economy

Research and development spending is a significant component of the GNP, and makes a major contribution to productivity growth.[3] The R&D-to-GNP spending ratio was at its highest point in 1964, when it reached 2.96 percent of GNP (see figure 2-2). Since that time the percentage fell to a low of 2.23 in 1978. Estimates for 1981 indicate that the ratio is likely to reach over 2.37 percent, in the latter year, with GNP and R&D expenditures growing at approximately the same rates. For comparisons between R&D spending in the U.S. and other countries, see the chapter of this report entitled "International Science and Technology."

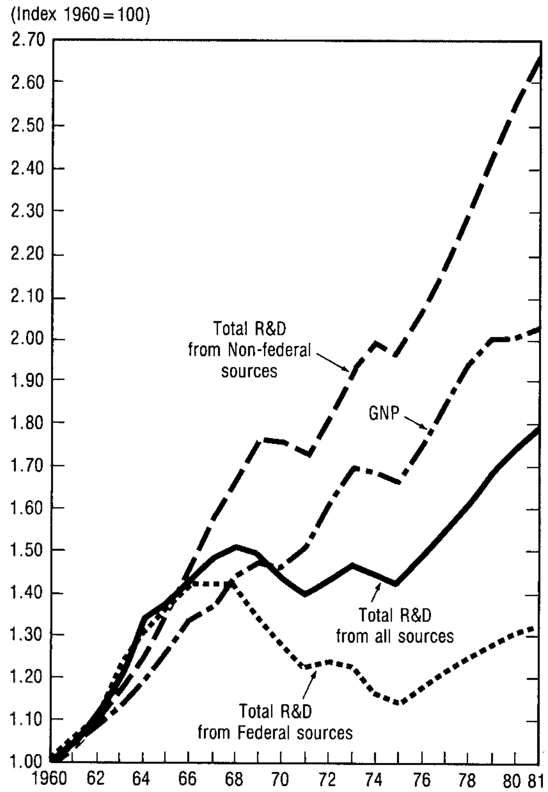
Research spending (combined basic and applied) also has declined significantly as a fraction of the GNP since 1964, when it stood at 1.00 percent. The ratio has held at about 0.80 percent since the mid-1970's. By comparing funding from R&D sources to the GNP (see figure 2-3), it can be seen that non-Federal R&D spending closely parallels changes in the GNP. The reasons for this pattern are not fully understood, but it is likely that non-Federal sources are susceptible to general economic conditions because of their primary profit-related objectives. The GNP and Federal R&D spending patterns are quite dissimilar, possibly because the Federal Government expends its resources on efforts to solve long-range national problems, an objective that is relatively unaffected by short-term variations in the national economy.

Sources of R&D Funds

One of the most persistent and, to many, the most important, characteristics of American science and technology is the diversity of institutional

[3]For a more thorough discussion of the literature dealing with relationships between R&D and productivity, see references to the topic in the chapters in this report entitled "International Science and Technology" and "Industrial Research and Technological Progress"; John W. Kendrick and Beatrice N. Vaccara, *New Developments in Productivity Measurement and Analysis* (Chicago: National Bureau of Economic Research, University of Chicago Press, 1980).

Figure 2-3
Relative change of GNP and Federal and national R&D expenditures (In constant 1972 dollars[1])



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Estimates are shown for 1979, 1980 and 1981. Index calculated from data on Appendix table 2-3.
REFERENCE: Appendix table 2-3.
Science Indicators—1980

sources of suppport.[4] Such multisource funding is important to research and development because it prevents unilateral control of R&D priorities, minimizes the possibility for major mistakes, and increases the opportunity for exploration in areas of importance to wider segments of society.

Each sector of the economy has its own needs and reasons for supporting R&D. For example, the industrial sector has economic gain as its primary goal, and its R&D effort is aimed toward this. The Federal Government focuses its support on relatively longer-term R&D activity directed toward the solution of national problems, and on R&D which is not likely to produce direct financial benefit, but which is expected to contribute to technical advance and public benefit.

[4]Jeffrey L. Sturchio and P. Thomas Carroll, "The Sciences In America, circa 1880," *Science*, vol. 209 (July 4, 1980), pp. 27-32.

Analysis of R&D support trends in various sectors of the economy can shed light on the relative balance among them. This information can also provide a rational basis for possible interventions if there are undesirable changes in support trends.

The major sources of funding for research and development are the Federal Government, industry, universities and colleges, and nonprofit institutions. Most of the R&D funds come from Federal and industrial sources, each providing approximately the same proportion of funds (about 48 percent) in recent years. This has not always been the case. In 1960, for example, most R&D funds were provided by the Federal Government, which accounted for 65 percent of the total, while industry provided 33 percent. The portion provided by Federal sources fell from the 1960 level largely because of reduced support for the manned space program coupled with reductions in defense R&D spending. Paralleling this reduction were increases in industrial R&D spending, due partly to increased support for regulatory-related R&D, and also to wider adoption of corporate strategies that place more emphasis on R&D as a source of future growth and new market opportunities.

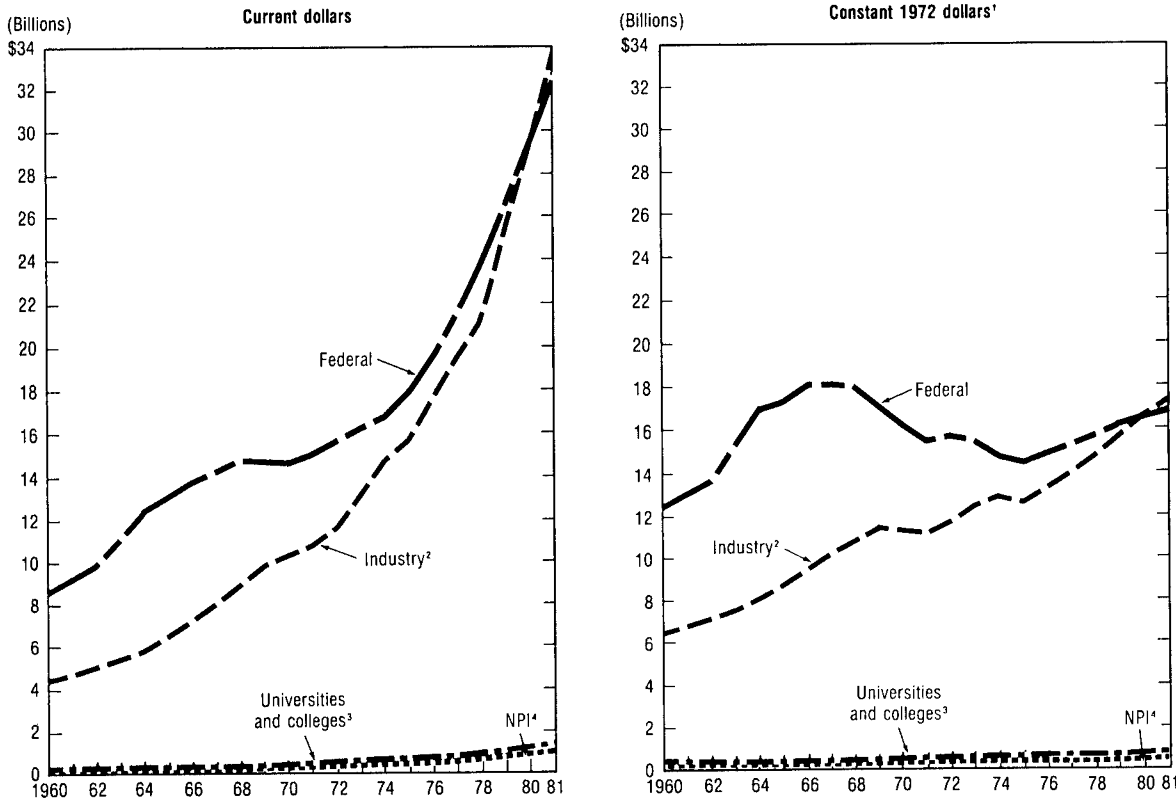
In constant dollars, both Federal and industrial R&D funding have grown in recent years (see figure 2-4). This growth is particularly important in the case of the Federal Government because it represents a reverse of the funding trend from the mid-1960's to the mid-1970's. Between 1976 and 1979, Federal expenditures grew at an average annual rate of about 2.8 percent, in contrast to an average annual decline of 2.2 percent between 1970 and 1975. Estimates for the period 1979 to 1981 indicate that Federal constant-dollar spending may stay at about the 1979 level. Constant-dollar R&D funding by industrial sources has had relatively steady growth since 1960. From 1976 to 1979, constant-dollar industrial funding rose at an average annual rate of 5.6 percent and is expected to grow steadily between 1979 and 1981. The constant dollar average annual growth in R&D funding by industrial sources that occurred between 1976 and 1979 parallels the 4.5 percent constant-dollar average annual growth in the GNP during the same period.

Universities and colleges and nonprofit institutions provide a relatively small share of R&D funds. In recent years, these sectors together provided approximately 4 percent of all R&D funds.

Performers of R&D

The Federal Government and industry are the Nation's primary supporters of R&D. However,

Figure 2-4
National expenditures for R&D by source



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
[2]Data are not available on industry resources for research in the psychological and social sciences.
[3]Includes state and local sources which accounted for almost half of these expenditures since 1970.
[4]Other nonprofit institutions.
NOTE: Estimates are shown for 1979, 1980 and 1981.
REFERENCE: Appendix table 2-4.

Science Indicators—1980

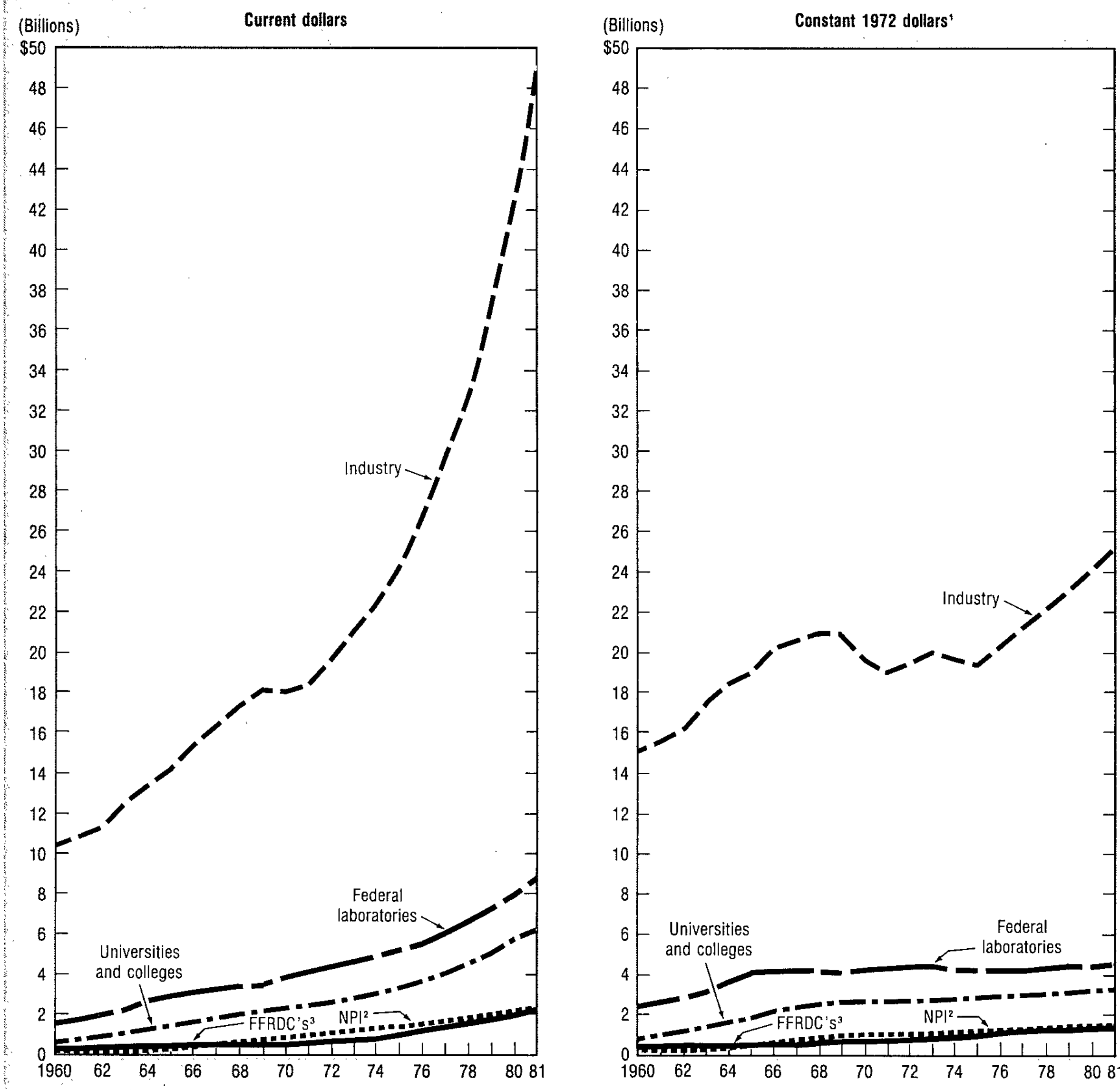
their roles in the performance of R&D are different. Some sectors are more qualified to conduct R&D programs than their sponsoring organizations.

The industrial sector performs most of the Nation's R&D. As a whole, industry accounts for approximately 71 percent of all R&D expenditures. This is so largely because the industrial sector performs a substantial amount of R&D in order to meet its own need for new products and processes and is, therefore, more prepared to take on additional activities. In addition, industry undertakes a substantial amount of development work, which generally is more expensive than basic and applied research.

When measured in constant dollars, R&D in industry has grown markedly since 1976 (see figure 2-5). From 1976 to 1979, expenditures advanced at an average annual rate of about 4 percent and are expected to continue this steady growth pattern through 1981. As pointed out in the previous section on sources of support, much of this spending growth comes from industry's own funds.

The Federal Government provides a substantial amount of money for in-house R&D activities through the various laboratories it operates. However, this support represents a small proportion of national R&D expenditures. In recent years, Federal performers have accounted for only 13 percent of all R&D spending. Universities and colleges, federally funded research and development centers administered by universities and colleges, and nonprofit institutions have accounted for the remainder of the R&D expenditures, with 9 percent, 3 percent, and 3 percent, respectively. The proportion of funds spent by these per-

Figure 2-5
National expenditures for R&D by performer



[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
[2] Other nonprofit institutions.
[3] Federally funded research and development centers administered by universities.
NOTE: Estimates are shown for 1979, 1980 and 1981.
REFERENCE: Appendix table 2-5.

Science Indicators—1980

formers has been relatively stable throughout the last decade.

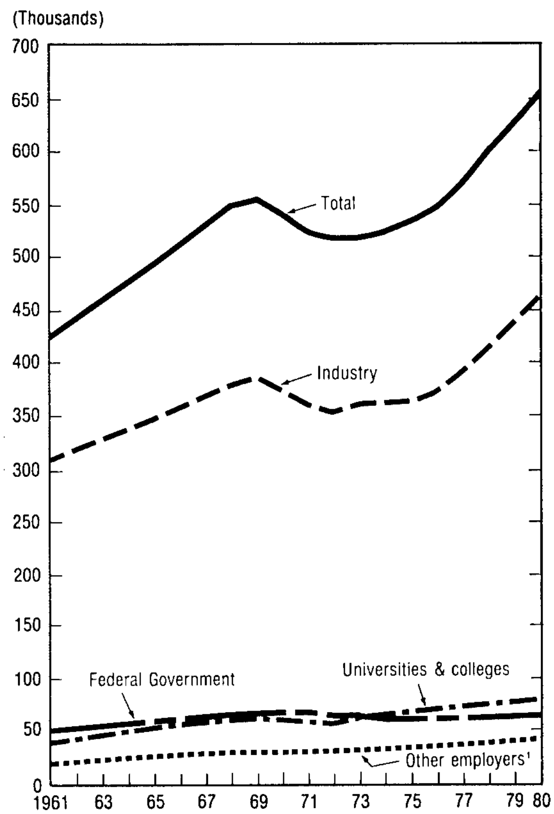
Scientists and Engineers

Expenditure patterns are important tools for quantifying levels of R&D activity. However, some measure of the human resources available to perform research and development is necessary in order to provide a complete picture of national resources for science and technology. Such information is also useful for validating the use of expenditure data as an activity surrogate because of the relation between overall expenditure and the amount of human effort devoted to R&D. However, this relationship could vary because of rapid increases in personnel costs or variations in the mix of cost components.

Since a period of decline from 1969 to 1972, there has been a continuous rise in R&D employment for S/E's (see figure 2-6). By 1980, an estimated 659,000 full-time-equivalent (FTE) scientists and engineers were active in R&D. Since industry is the largest performer of R&D, it also employs more scientists and engineers in R&D than all other sectors combined. In 1980, this sector accounted for 71 percent of the total.[5] Universities and colleges, with about 83,000 FTE scientists and engineers in 1980, were the next largest employing sector, with about 13 percent of the total, followed by the Federal Government with 67,000, or 10 percent. The FTE of scientists and engineers employed in Federal sector R&D in 1980 remains about 5 percent below the 1970 peak, which was largely due to defense- and space-related R&D activities. However, in universities and colleges, there have been steady increases throughout the mid-1970's, and 1980 FTE employment levels surpassed those of 1970 by 20 percent. The chapter of this report entitled "Scientific and Engineering Personnel" provides a more comprehensive treatment of this and other aspects of the employment characteristics of R&D scientists and engineers.

Figure 2-6

Scientist and engineer full-time equivalent used in R&D by sector



[1]Includes scientists and engineers employed in R&D in other nonprofit institutions and FFRDC's administered by universities.

NOTE: Estimates are shown for 1979 and 1980.

REFERENCE: Appendix table 2-6.

Science Indicators—1980

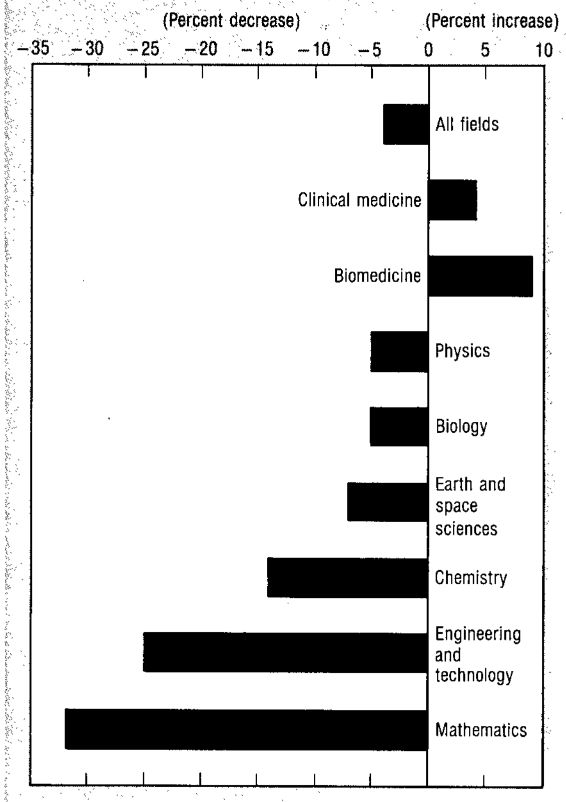
LITERATURE OUTPUT OF U.S. RESEARCH

In addition to indicators of the financial and human resources committed to the Nation's research effort, it is important to examine trends resulting from that effort. Data on the scientific and technical literature found in leading journals can be used to describe rates of growth or decline, prominence of certain research-performing sectors in given fields, and the level of dependence of the research enterprise on specific sector's work. Indicators of research literature may correspond more to developments in a particular research field than do measures to research resources. It is in the cumulative process that the development of new knowledge moves ahead.

Overall, the number of U.S. articles fell 4 percent from 1973 to 1979 (figure 2-7), compared to a slight increase of 1 percent for the rest of the world. U.S. articles declined in six out of the eight fields examined. Especially noticeable have been the 6-year declines in U.S. mathematics articles (32 percent), engineering and technology articles (25 percent), and chemistry articles (14 percent). Articles in these fields from 1973 to 1979 by authors from outside the U.S. declined, respectively, 7 percent,

[5]Because many scientists and engineers work in R&D part time (e.g., in universities and colleges), an approximate full-time-equivalent (FTE) figure is used exclusively in this discussion. See *National Patterns of Science and Technology Resources 1980*, National Science Foundation (NSF 80-308), p. 33.

Figure 2-7
Percent changes in the number of science and technology articles[1] by U.S. authors by field: 1973 to 1979



[1]Based on the articles, notes and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

REFERENCE: Appendix table 2-7. Science Indicators—1980

21 percent, and 1 percent.[6] Therefore, in these fields, the United States experienced significantly greater shrinkage of its annual research literature than did other countries.[7] Only the number of clinical medicine and biomedicine articles rose over this 6-year period.

The various sectors largely retained their share of the distribution of research articles over the 1973-79 period, with academic researchers writing slightly more of the total articles in biology and clinical medicine (see appendix tabie 2-8).

Looking again at U.S. mathematics and engineering and technology articles, where the overall decreases were very large, most of the decline in mathematics articles occurred in the university and college sector; however, academic articles in engineering and technology fell only 21 percent compared to 28 percent for the Federal Government, 33 percent for industry, and 45 percent for nonprofit institutions.

In all the major research-performing sectors, there is evidence of a a considerable amount of cooperative research being conducted with other sectors (see figure 2-8).[8] For example, in 1979, from one-third to two-thirds of the scientific and technical articles were co-authored by researchers from organizations in different research-performing sectors—highest for nonprofit institutions (65 percent) and lowest for industry (32 percent). The greatest increase in this index of cooperative research occurred in Federal Government research, which experienced above-average increases in seven of the eight major fields. If this trend continues, it may signal the more rapid utilization of current research findings, particularly if the nonindustrial research sectors cooperate with the industry researchers whose corporate setting is more likely than the others to provide opportunities for the application of that research.

Another aspect of the relationship between research-performing sectors is the dependence of the research community on previous work done not only within a given sector but in other sectors as well. One way of measuring this dependence or conversely this influence, is to identify the use made of previous research, as found in references and source footnotes in articles. Since some sectors have a much larger share of the research that is covered by this literature data base (see appendix table 2-8), it is necessary to adjust the raw counts of citations.[9] Table 2-1 shows that of the three major sectors, academic research is cited in almost all fields more than could be explained by its share of all U.S. articles—for example, 27 percent more than expected in the case of engineering and technology in 1977. University researchers also seem more prominently quoted than other sectors in chemistry, the earth and space sciences, and biology. The Federal Government is also a disproportionate source of prior research for U.S. scientists, but in only three fields in 1977: clinical medicine, mathematics, and biomedicine. Only in physics did industrial research have more influence than other sectors had.

[6]Based on appendix table 1-12.

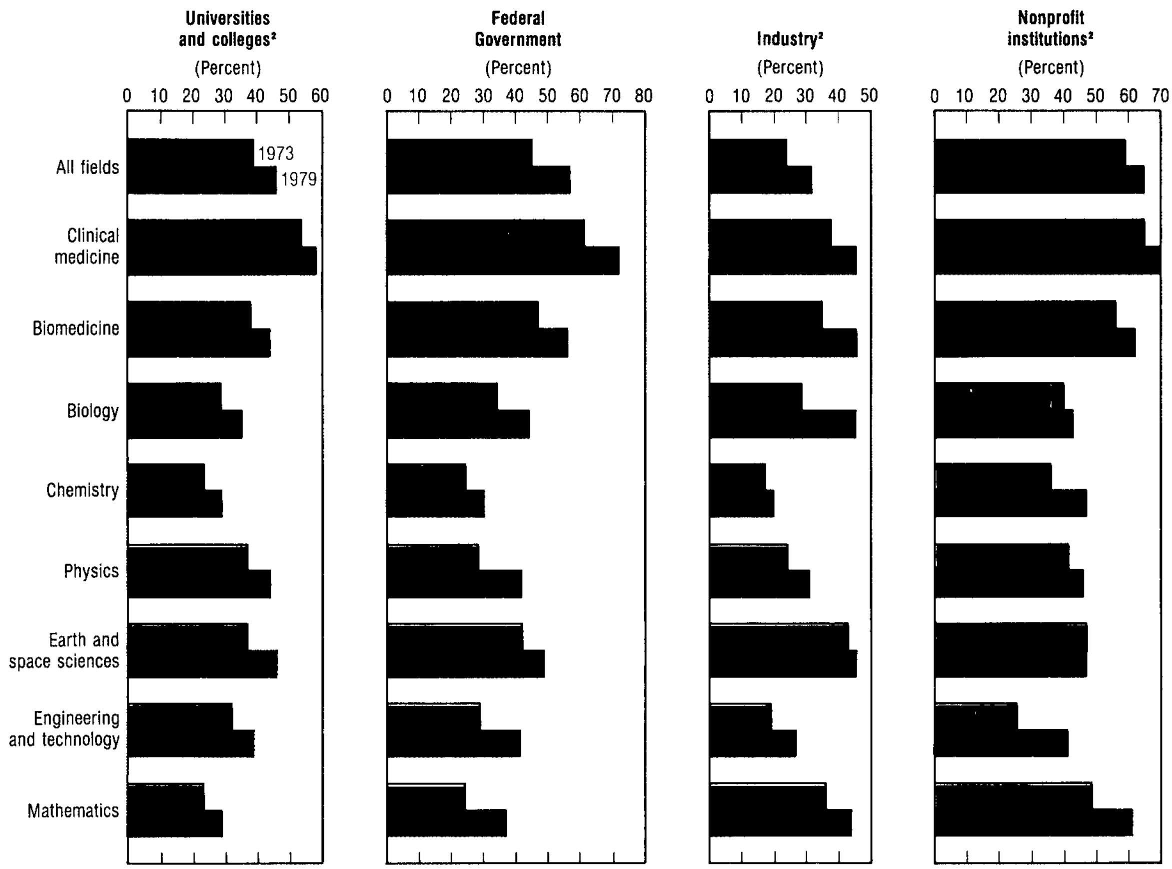
[7]See the chapter on "International Science and Technology" for more detailed information.

[8]See appendix table 3-7 for separate information on basic and applied research articles written by researchers from more than one sector.

[9]The method chosen here is to normalize the share of all U.S. citations to that sector by the share of the publications or articles that sector has of the total.

Figure 2-8

Index[1] of cooperative research based on scientific and technical articles, by field and selected research-performing sectors



[1]Consisting of the percentage of all articles which were written by U.S. scientists and engineers in a given organization with S/E's from another organization: e.g., if S/E's from one university co-author an article with S/E's from another university or a corporation, it is assumed here that there was some degree of cooperative research performed. The data are from over 2,100 of the influential journals carried on the *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2]Excluding the federally funded research and development centers administered by these sectors.

REFERENCE: Appendix table 2-9.

Science Indicators—1980

However, when only citations from *outside* an originating sector are considered, there are some differences in the leading sectors in each of these fields.[10] Evaluated in this manner, university research has the highest influence ratios, compared to the other sectors, in earth and space sciences, biology, chemistry, and physics (table 2-1). The greatest influence for articles by Federal Government S/E's is found in clinical medicine, mathematics, and engineering and technology while industry accounts for the highest biomedicine influence ratios.

CHARACTER OF R&D ACTIVITIES

Research and development encompasses an extremely broad spectrum of activities ranging from the search for new knowledge about man and his environment to the development of new products and processes. The assessment of R&D expenditures presented thus far describes the total level of effort but does not reveal the changes taking place in the R&D activities. What balance is being struck between expenditures for research and those

[10]Ratios of table 2-1 for citing from *outside* a sector all are less than 1.00 because of a universal tendency to cite articles from one's own field, sector, nation, or level of research.

for development? What is the mix between the two major types of research, basic and applied? Which sectors are primarily responsible for supporting basic and applied research? Who principally supports developmental projects?

In order to shed light on these questions, the following sections analyze funding trends for research as well as for development, and examine patterns of support for basic and applied research.[11] Expenditure data for each type of activity reflect the Nation's relative emphasis on the advancement of basic scientific knowledge, application of knowledge, and development of products and processes used by the public.

[11] Complete definitions of the terms "basic research," "applied research," and "development" as used by the NSF in its data collection activities are provided in appendix table 2-12 where data by character of work are presented. Generally, basic research is directed toward increases of knowledge in science, applied research is directed toward practical application of knowledge, and development entails the systematic use of knowledge gained from research.

Development and Total Research

The Nation invests the largest part of its R&D resources in development—projects directed toward production of useful materials, devices, systems, and methods. Typically, development accounts for about two-thirds of total national R&D expenditures (see figure 2-9). Between 1976 and 1979, constant-dollar development spending grew at an average annual rate of 4.2 percent. Estimates for 1980 and 1981 indicate that development expenditures are likely to continue to advance. Industry accounts for the largest fraction of development funding, providing approximately 55 percent of all development funds. The Federal Government is also a major contributor, providing 44 percent of the total.

Table 2-1. Relative citation ratios[1] for 1977 U.S.-authored articles[2] by field and selected sector

Sector	All U.S. citations		Citations from outside the sector	
	Ratio	Field	Ratio	Field
Universities and colleges	*1.27	Engineering & technology	* .80	Earth & space sciences
	*1.10	Chemistry	.77	Clinical medicine
	*1.07	Earth & space sciences	.68	Biomedicine
	*1.06	Biology	.68	Mathematics
	1.02	Biomedicine	* .62	Biology
	1.01	Clinical medicine	* .61	Chemistry
	1.01	Physics	* .61	Physics
	.99	Mathematics	.56	Engineering & technology
Federal Government	*1.26	Clinical medicine	* .96	Clinical medicine
	*1.18	Mathematics	* .82	Mathematics
	*1.05	Biomedicine	.67	Biomedicine
	1.00	Engineering & technology	* .66	Engineering & technology
	.84	Earth & space sciences	.62	Earth & space sciences
	.84	Biology	.56	Physics
	.83	Physics	.52	Chemistry
	.82	Chemistry	.47	Biology
Industry	*1.09	Physics	.74	Mathematics
	.98	Mathematics	* .73	Biomedicine
	.95	Biomedicine	.58	Physics
	.81	Engineering & technology	.51	Clinical medicine
	.79	Biology	.50	Biology
	.75	Clinical medicine	.42	Engineering & technology
	.73	Chemistry	.41	Chemistry
	.52	Earth & space sciences	.39	Earth & space sciences

[1] A citation ratio of 1.00 reflects no over- or under-citing of each sector's literature, whereas a higher ratio indicates a greater influence, impact, or utility than could be explained by the number of the sector's publications for that year. For example, the clinical medicine literature by Federal Government authors received 26 percent more citations by all U.S. authors than could be accounted for by the Federal Government's share of articles published in 1977.

[2] Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. For the size of this data base, see appendix table 1-12.

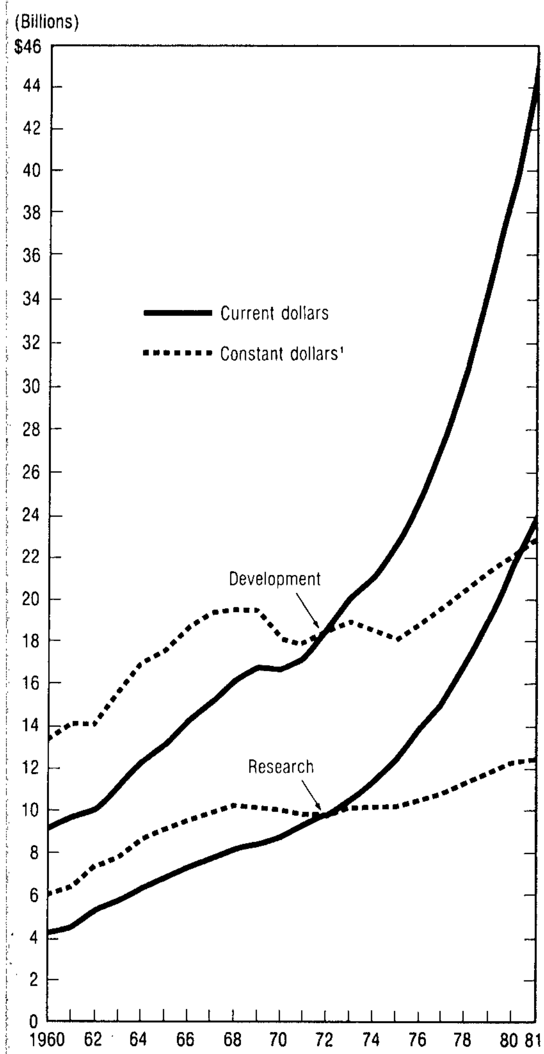
[3] See appendix table 1-13 for a description of the subfields included in these fields.

NOTE: The * indicates that this field is most highly cited in this sector.

REFERENCE: Computer Horizons, Inc., unpublished data.

Science Indicators—1980

Figure 2-9
Research and development expenditures



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Estimates are shown for 1979, 1980 and 1981.
REFERENCE: Appendix table 2-10. Science Indicators—1980

Basic and applied research activities account for approximately one-third of all R&D spending. Over the years, there have been some changes in the balance between total research and development. In 1960, research accounted for 31 percent of the total; the share grew to 36 percent by 1976 and has remained at that level ever since. Contributing to the increased share of research spending has been the strong and consistent Federal support for both basic and applied research. In terms of constant dollars, research spending has expanded significantly from 1976 to 1979, growing at an estimated average annual rate of 4 percent. It is expected to level off in 1980 and 1981 (see figure 2-10).

To identify shifts in R&D emphasis, it is useful to examine the funding shares of basic and applied research, as well as the level of support for each. In constant dollars, total national expenditures for basic research had been declining since the late 1960's, but have grown in recent years[12] (see figure 2-11). From 1976 to 1979, constant-dollar basic research support grew at an average annual rate of 5.6 percent.

Spending for applied research rose sharply in 1976, following a period of relative stability from the mid-1960's to the mid-1970's. Between 1976 and 1979, constant-dollar spending for applied research grew at an average annual rate of about 3.2 percent. Estimates through 1981 suggest continued advances, possibly at a slower rate. In recent years, Federal and industrial sources provided approximately equal amounts for applied research (see figure 2-12), or about 47 percent each in 1979. Constant-dollar applied research support between 1976 and 1979 grew substantially in the case of industrial sponsors whose funding increased at an average annual rate of 4.7 percent, and at an estimated 4.8 percent per year between 1979 and 1981. In recent years, Federal support has remained within 5 percentage points of the 1976 figure, and estimates suggest that this will be the case through 1981.

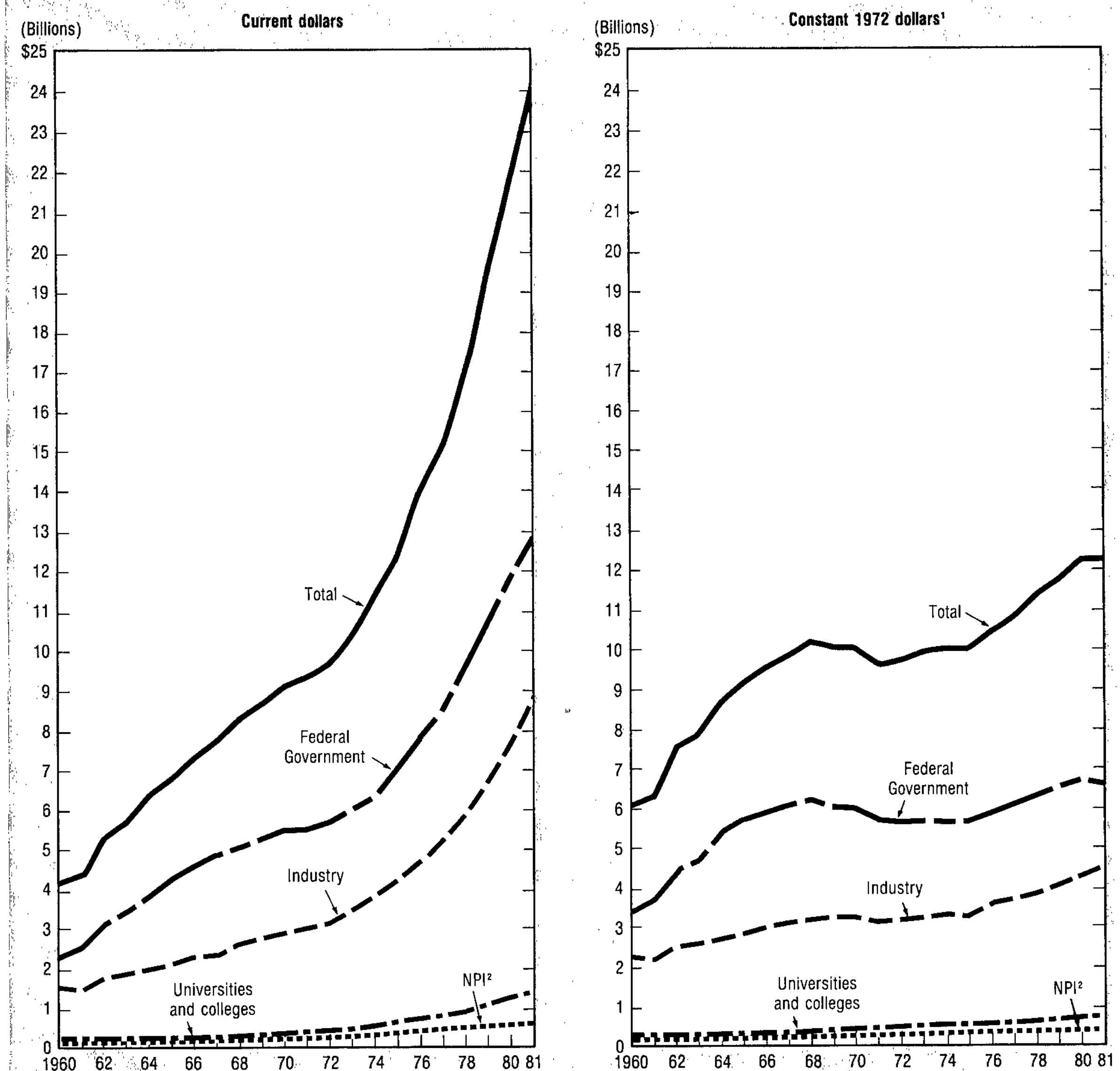
FUNCTIONAL AREAS OF FEDERAL R&D FUNDING

While each Federal agency supports R&D related to its mission, analysis of agency spending patterns alone cannot adequately reflect the extent to which Federal R&D spending is focused on specific scientific, technical, and social problems. Therefore, this section identifies the major segments into which Federal R&D resources are distributed.[13] Such a presentation provides a basis for

[12]See the chapter in this report entitled "Resources for Basic Research" for a more complete discussion of basic research expenditures and other indicators of basic research activity.

[13]Throughout the following discussion of Federal R&D functional areas, it should be noted that estimates given for 1980 and 1981 may change as a result of congressional action on agency budget requests. Data regarding the functions are presented in terms of Federal obligations. Obligations represent the amounts for orders placed, contracts awarded, professional services received, and similar liabilities incurred during a given period, regardless of when the funds were appropriated. Expenditures (outlays), which are discussed in other sections of this chapter, represent amounts for checks issued and cash payments made during a given period, regardless of when the funds were appropriated.

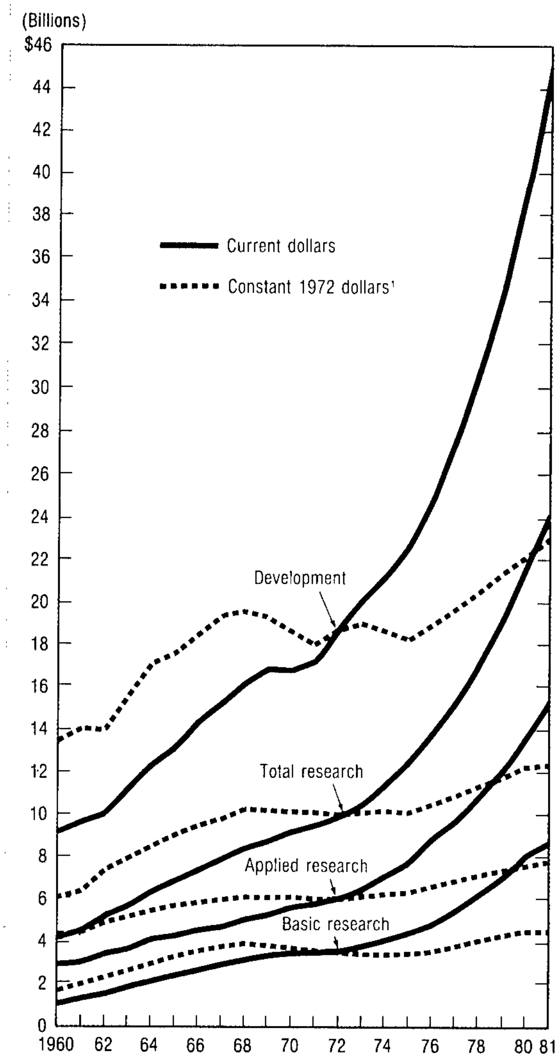
Figure 2-10
Total research expenditures by source



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
²Nonprofit institutions.
NOTE: Estimates are shown for 1979, 1980 and 1981.
REFERENCE: Appendix table 2-11.

Science Indicators—1980

Figure 2-11
National R&D expenditures by character of work



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Estimates are shown for 1979, 1980 and 1981.
REFERENCE: Appendix table 2-12.

Science Indicators—1980

assessing Federal R&D priorities and for assistance in determining whether certain areas of national interest are receiving sufficient support, or deciding whether there is a proper balance of support. As figure 2-13 demonstrates, Federal support for the Nation's R&D activities can be broken down into three major categories: national defense, space, and civilian R&D, the latter referring to all nondefense and nonspace activities. Between 1976 and 1981, current-dollar R&D obligations in each area have grown markedly, with defense and civilian functions advancing 77 and 68 percent, respectively, above the 1976 level, and space funding growing by 58 percent. Even more dramatic is the recent increase for defense R&D obligations. Between 1980 and 1981 these obligations grew by 23 percent, compared with increases of 7 and 1 percent, respectively, for space and civilian research and development. After adjusting for inflation, however, quite a different picture emerges, with defense advancing about 13 percent between 1980 and 1981, while space and civilian R&D obligations declined somewhat.

National Defense

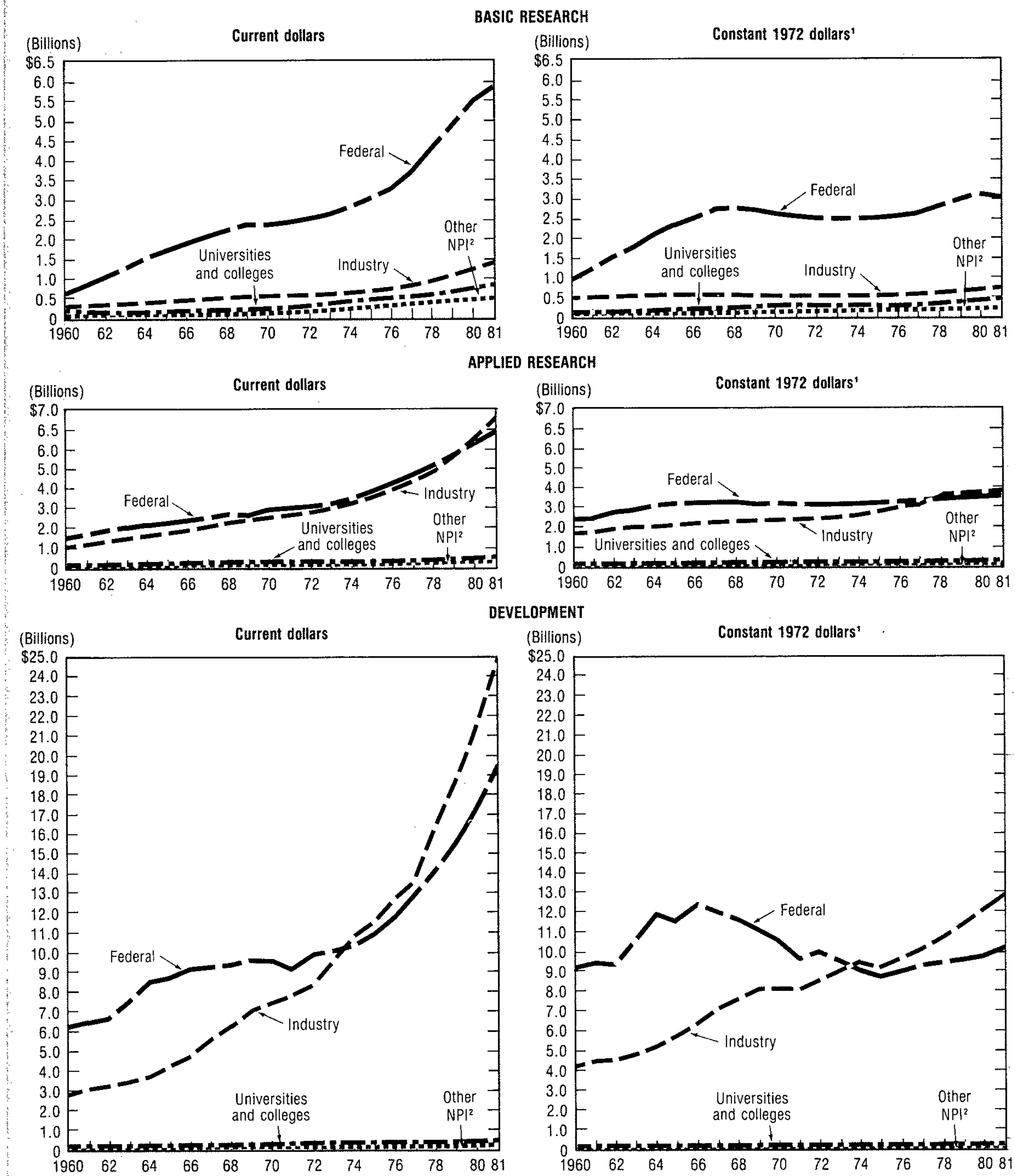
National defense receives the largest share of the Federal R&D resources, about 52 percent of the total (see figure 2-14). Obligations for space research and development represent about 14 percent while all other functional areas account for approximately 34 percent. Defense R&D obligations, as a percentage of the total, have held between 47 and 54 percent since 1971, but the share declined somewhat over the period 1973 to 1980, dropping to the 47 percent level in 1980. (See appendix table 2-17.) In current dollars, defense R&D obligations will reach an estimated $18 billion in 1981. The increase estimated for 1981 reflects a strong emphasis on defense in the overall budget. Among the areas included in the 1981 budget were the DOD technology base, strategic R&D programs such as the MX missile, intelligence and communications programs, and atomic energy defense activities conducted by DOE such as the inertial confinement fusion program and the defense waste management program.

Space R&D

The space research and technology budget category accounts for an estimated 14 percent of all 1981 Federal R&D obligations. This percentage has declined since 1971, when it was 19 percent, and has remained at about 14 percent between 1977 and 1981. In current dollars, space R&D obligations are estimated at nearly $5 billion in 1981, an increase of about 7 percent over 1980. However, after accounting for inflation, 1981 obligations declined somewhat from the 1980 level. The fiscal year 1981 budget reflected a continued commitment to the development and initial operation of the space shuttle, with the first flight taking place in April 1981. Included in the budget for 1981 was continued support for a gamma ray observatory. Support was also provided for further development and testing of space remote sensing systems and techniques for earth resources surveys.

Figure 2-12

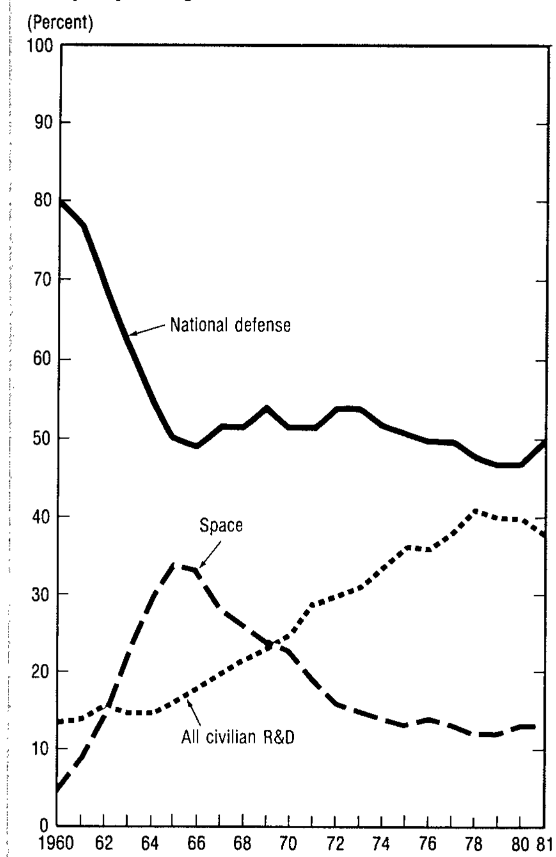
National R&D expenditures by character of work and source of funds



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
²Other nonprofit institutions.
NOTE: Estimates are shown for 1979, 1980 and 1981.
REFERENCE: Appendix tables 2-13, 2-14 and 2-15.

Science Indicators—1980

Figure 2-13
Percent of Federal obligations for R&D by major budget function



NOTE: Estimates are shown for 1980 and 1981. Percentages calculated from unrounded data.
REFERENCE: Appendix table 2-16. Science Indicators—1980

Civilian R&D

This category, consisting of 14 specific areas of science and technology, encompasses all of the nondefense and nonspace R&D missions supported by the Federal Government. Civilian R&D, as a percentage of all Federal R&D obligations, has grown substantially since 1971. In that year it accounted for 28 percent of the total, but it has grown to an estimated 34 percent in 1981. Between 1980 and 1981, civilian obligations are estimated to grow at about 1 percent, well below the rate of inflation. This is the area in which the public would most like to have its R&D tax dollars spent.[14]

[14] See the chapter entitled "Public Attitudes Toward Science and Technology" for a more complete discussion of public preferences regarding R&D spending and other aspects of opinion toward science and technology in general.

Among the general population, the improvement of health care ranks as the number one R&D priority, and, in this instance, the public preference coincides with the Federal Government's top-ranked civilian R&D priority. The health functional area receives the largest fraction (about 32 percent) of all civilian R&D obligations (see table 2-2). Health R&D obligations are projected to reach $3.8 billion in 1981. Among the research receiving special attention in 1981 are efforts by the National Institutes of Health in the areas of environmental health, arthritis, metabolic and digestive diseases.

Energy is the second largest civilian R&D category, and the second-ranked area in terms of public preference for R&D tax dollar expenditure. This area represents about 29 percent of all Federal civilian R&D obligations in 1981. Unlike health R&D, however, estimates for 1981 indicate a leveling off at about the 1980 level, although some areas, including basic energy research and magnetic fusion programs, are expected to receive increases. Nuclear fission and fossil energy R&D are scheduled for decreases. Obligations in energy R&D continue to be made in the context of supporting longer-term, high-risk R&D programs to complement work of the private sector.

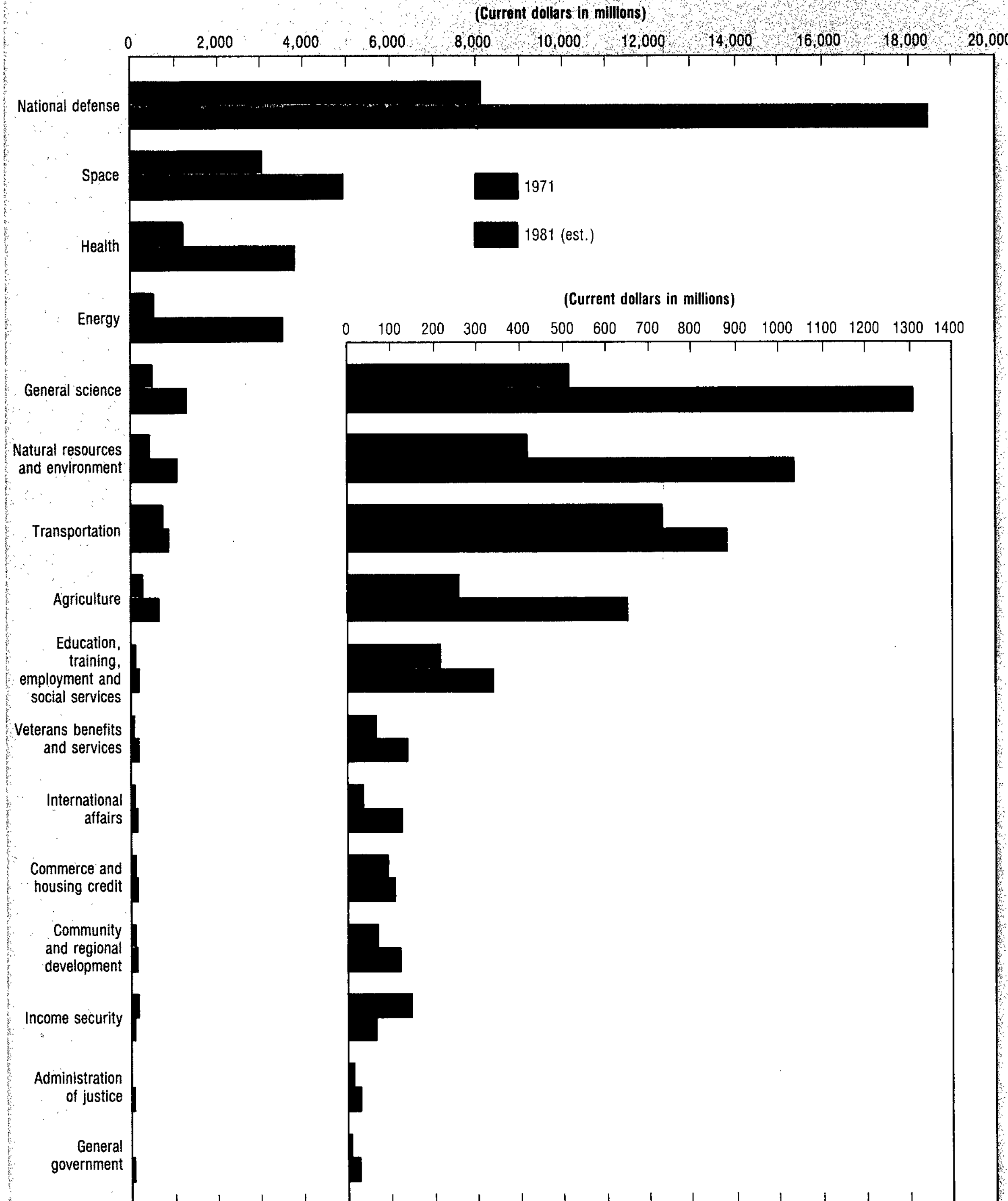
FEDERAL FUNDS FOR R&D PLANT

The tools of the trade in research and development often take the form of major facilities such as nuclear reactors, high-energy accelerators, telescopes, wind tunnels, and other such items. Expenditures for R&D plant tend to vary considerably over relatively short time periods as a result of new and costly investments, followed by completion of the facility and associated declines in facility spending (see figure 2-15). For example, the rapid growth of constant-dollar R&D plant expenditures during the early 1960's was chiefly due to the expansion of NASA's intramural facilities, and the decline in the late 1960's largely reflects their completion. The increases after 1972 reflect increased spending for energy-related facilities—particularly equipment for work in fusion power research and high-energy physics, support of space shuttle facilities by NASA, and the building of three major research facilities by NIH.

Between 1979 and 1980, Federal expenditures for R&D plant advanced by nearly 30 percent in constant dollars. This major increase was produced primarily by increased spending by DOE. It is projected that increases will continue into 1981, at a somewhat slower rate than in 1980.

The principal beneficiaries of the increased constant-dollar obligations in the late 1970's and early

Figure 2-14
Federal obligations for R&D by budget function



Data for 1971 are shown in obligations and data for 1981 are shown in budget authority.
NOTE: Estimates are shown for 1981
REFERENCE: Appendix table 2-17.

Science Indicators—1980

Table 2-2. Distribution of Federal R&D funding among civilian areas

R&D function	Percent of the Federal R&D total 1977	1978	1979	1980	1981	Percent of the civilian Federal R&D total 1977	1978	1979	1980	1981
Health	11.0	11.2	11.7	11.7	10.8	30.0	29.3	30.1	30.7	31.5
Energy	10.7	11.8	11.9	11.4	9.9	29.3	30.9	30.7	29.9	29.0
General science	4.1	4.0	3.9	3.9	3.7	11.1	10.4	9.9	10.2	10.7
Natural resources and environment	3.1	3.4	3.5	3.2	2.9	8.6	8.9	9.0	8.3	8.5
Transportation	3.0	2.9	2.8	2.8	2.5	8.1	7.6	7.1	7.4	7.2
Agriculture	1.9	1.9	1.9	1.9	1.8	5.2	4.9	4.9	4.9	5.3
Education, training, employment, and social services	1.0	1.3	1.2	1.5	1.0	2.6	3.4	3.1	3.9	2.8
Community and regional development	.4	.3	.4	.3	0.3	1.2	.9	1.1	.9	.9
International affairs	.3	.2	.4	.4	.3	.8	.6	1.0	1.0	1.0
Veterans benefits and services	.4	.4	.4	.4	.4	1.2	1.1	1.1	1.0	1.1
Commerce and housing	.3	.3	.3	.3	.3	.8	.8	.8	.8	.9
Income security	.2	.3	.2	.1	.2	.6	.7	.5	.4	.5
Administration of justice	.1	.2	.2	.1	.1	.3	.4	.4	.4	.2
General government	.1	.1	.1	.1	.1	.1	.2	.2	.2	.2

SOURCE: National Science Foundation, *Federal R&D Funding by Budget Function, Fiscal Years 1979-81* (May 1980), p. 3; and unpublished data.

1980's are the Federal intramural laboratories, FFRDC's, and industry. Federal R&D plant obligations to universities and colleges have fallen steadily in constant-dollar terms (see figure 2-16). It is estimated that in 1981, academic sector obligations are less than one-third of what they were in 1970 and one-tenth of the 1966 level, which was the peak constant-dollar year. By comparison, in recent years obligations to industry, Federal intramural laboratories, and FFRDC's administered by universities have had relatively strong growth. Over the last decade, there has been a slight increase in the proportion of Federal funds for R&D plant out of all Federal R&D and R&D plant outlays. In 1970, this fraction was about 4 percent, but estimates for 1980 indicate a probable increase to approximately 6 percent.

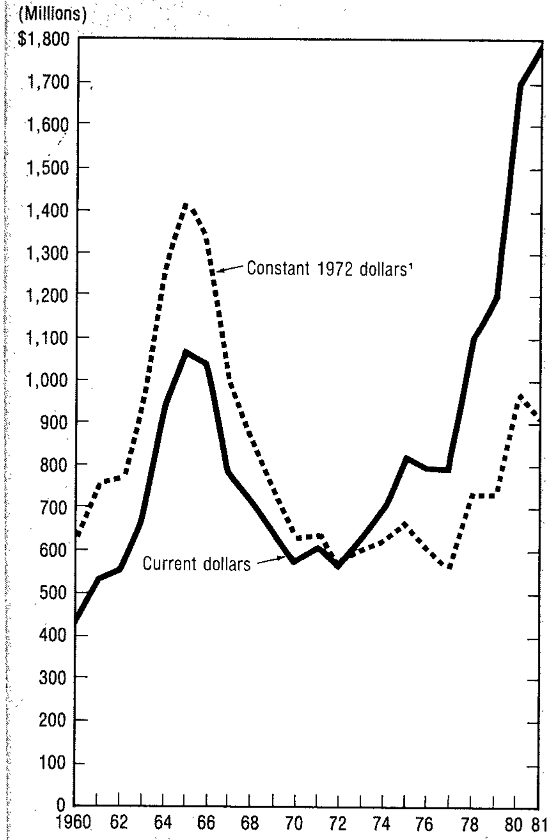
SUMMARY

Funds committed to research and development in the United States are at the highest levels in history, amounting to an estimated $69 billion in 1981. However, inflation has affected the availability of funds for scientific and technological activity, reducing the buying power of current dollars by about half. The estimated 1981 level of R&D spending in real dollars is less than 3 percent higher than the expected 1980 level and only 20 percent above that of 1976. Basic research spending has grown more rapidly in recent years than has spending for applied research or development, advancing at an average annual constant-dollar rate of over 5.6 percent from 1976 to 1979. Applied research, measured in constant dollars, advanced at an average annual rate of almost 3.2 percent from 1976 to 1979, while development grew at a 4.2 percent rate. Applied research and development both are expected to remain stable or show slight growth in the early 1980's. Constant-dollar spending by Federal and industrial sources has grown in recent years. In the Federal sector, expenditures grew at an average annual rate of 2.8 percent between 1976 and 1979. Estimates for 1980 and 1981 indicate that constant-dollar spending will remain at about the 1979 level. In the industrial sector, spending grew at an average rate of 5.6 percent from 1976 to 1979 and is expected to continue to increase in 1980 and 1981.

Industry, the largest performer of R&D, accounts for about 71 percent of all R&D spending. Between 1976 and 1979, constant-dollar expenditures in this sector grew at an average annual rate of about 4 percent and are expected to continue this steady growth through 1981.

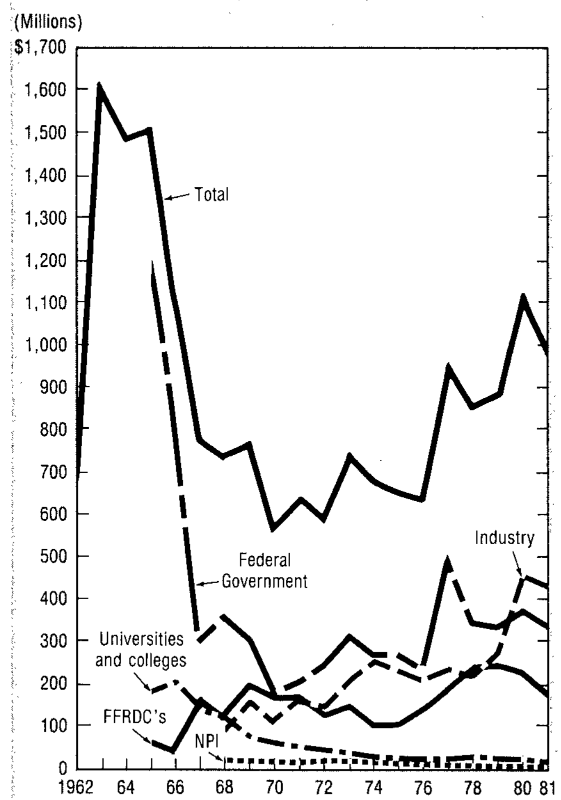
Among the functional areas in which R&D funds are spent, defense is by far the largest, representing about half of the total. Space and civilian spending accounts for 14 and 34 percent, respectively. Defense R&D spending has received

Figure 2-15
Federal expenditures for R&D plant



¹GNP fiscal year implicit price deflators used to convert current dollars to constant 1972 dollars.
Note: Estimates are shown for 1980 and 1981.
REFERENCE: Appendix table 2-18. Science Indicators — 1980

Figure 2-16
Federal obligations for R&D plant in constant dollars¹ by performer



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
²Federally funded research and development centers administered by universities.
REFERENCE: Appendix table 2-19. Science Indicators—1980

special attention in 1981, with current-dollar obligations growing over 23 percent between 1980 and 1981, compared with growth of 7 percent for space R&D and 1 percent for civilian R&D.

INDIRECT FEDERAL SUPPORT FOR RESEARCH AND DEVELOPMENT

Analysis of support for R&D in the United States typically emphasizes data on obligations and direct expenditures because they offer the strongest basis for assessing the primary resources specifically budgeted for research and development activities. However, R&D is also supported in indirect ways. To provide a more complete view of how various resources affect R&D, this section discusses some of the indirect means through which science and technology are supported in the United States.[15]

Indirect support is discussed here in terms of funds provided for R&D through the Federal Government's support for Independent Research and Development and funds made available to industry through special tax treatment of R&D expenditures. There may also be other ways in which R&D

[15]The National Science Foundation commissioned several individuals to prepare papers on various aspects of the indirect support topic. The material contained here was drawn, in part, from those papers. The authors who prepared papers were George Heaton, M.I.T.; F.A. Long, Cornell University; N.C. Robertson, Consultant; and Willis H. Shapley, American Association for the Advancement of Science. See *Papers Commissioned as Background for Science Indicators—1980*, vol. II: Indirect Mechanisms of Federal Support of R&D, National Science Foundation, 1981.

is indirectly supported. However, of those mentioned here, perhaps the one most readily measurable is the first, which deals with funds provided for independent research and development (IR&D). In the case of IR&D, the funds reported here do not represent additional funds not reported in national R&D totals, but rather a further disaggregation of those national totals.

Independent Research and Development

Independent research and development is the name that has been given to certain R&D activities of industrial contractors selling goods or services to the Federal Government, primarily to DOD and NASA. This R&D is "independent" in that it is conducted by the companies on their own initiative and under their own control. The costs associated with this R&D are indirect and shared by all of a company's customers. A portion of the cost of IR&D is recovered by the companies through overhead charged to the Government on cost-reimbursable type contracts, in keeping with agreements as to what share of total company IR&D corporate activities are appropriate for Federal reimbursement as an allowable indirect cost.[16]

Typically, a company which receives Federal IR&D funds must submit to the agency sponsoring its work a portfolio of R&D projects which it has planned in areas related to its primary R&D and procurement contracts. The sponsors review each project and decide whether the work is appropriate for Federal reimbursement under the IR&D program. Thus, some assurance is provided that the R&D is relevant to the sponsoring agency's R&D mission. The Government has three major objectives for such support: to create an environment which encourages development of innovative concepts for defense and space systems and equipment; to develop technical competence in many contractors who can then respond competitively to Government-generated requests for proposals; and to contribute to the economic stability of contractors by allowing them the technical latitude to develop a broad base of products.[17]

Bid and proposal (B&P) activities of contractors, while generally not regarded as R&D, are closely related to IR&D and are handled together with IR&D by DOD and NASA in contract administration. B&P costs are those incurred by a company to prepare proposals for new contracts. From the company's standpoint they are, like IR&D, a general overhead expense necessary to stay in business—an expense that must be recovered in future sales. Some of the work required in B&P activities may be quite similar to IR&D. In complex competitive procurements, for example, B&P activities may include extensive technical and engineering studies of alternate concepts for the proposal, and even experimental R&D work on key technical problems to provide technical backup to the proposals submitted. B&P costs are administered in the same way as IR&D, except that there is no technical evaluation of company B&P plans.

The Department of Defense and NASA have, through IR&D payments, underwritten considerable corporate R&D activity. In 1979, for example, major contractors of these agencies received $762 million in support for IR&D, more than 90 percent of which was provided by DOD (see table 2-3).

Table 2-3. Historical statistics on IR&D reimbursed by DOD and NASA to major contractors (Millions of dollars)

Year	DOD	NASA	Total
1964	270	50	320
1965	274	61	335
1966	315	69	384
1967	369	58	427
1968	410	61	471
1969	468	43	511
1970	436	44	480
1971	354	41	395
1972	392	40	432
1973	441	38	479
1974	457	39	496
1975	501	40	541
1976	544	41	585
1977	598	46	644
1978	643	49	692
1979	708	54	762

SOURCE: Annual Defense Contract Audit Agency (DCAA) Report, "Summary of IR&D and B&P Costs Incurred by Major Defense Contracts" and NASA, unpublished data.

As shown in table 2-4, a substantial portion of corporate IR&D costs are not reimbursed by spon-

[16] See the Defense Acquisition Regulations (formerly the Armed Services Procurement Regulations), Section 15-205.35, and U.S. Department of Defense Instruction 5100.66, January 7, 1975, and December 8, 1976, for a detailed description of the reimbursement guidelines for IR&D efforts. For additional information regarding Federal IR&D, see David D. Acker, "Independent R&D: Key to Technological Growth," *Defense Systems Management Review*, vol. 3, (Winter 1980), pp. 43-57; Howard Emery Bethel,"An Overview of DOD Policy for and Administration of Independent Research and Development," Defense Systems Management School, Defense Documentation Center, No. ADA013362, May 1975.

[17] U.S. Department of Defense Instruction 5100.66.

soring agencies.[18] In 1979, some $587 million was deemed inappropriate for payment under IR&D guidelines; thus, this amount may be thought of as part of industry's own contribution to national R&D investment. It is also noteworthy that from 1977 to 1979, a smaller fraction of all of industry's IR&D costs have been accepted as eligible for reimbursement under the IR&D program (72 percent in 1979 versus 77 percent in 1977). In addition, there has been a slight decline in the percentage of funds actually reimbursed out of those considered eligible for reimbursement. This figure was 54 percent in 1977 but dropped to 50 percent in 1979.

Table 2-4. Statistics relating to IR&D for major DOD and NASA contractors (Millions of dollars)

	1977	1978	1979
Total industry IR&D direct cost incurred	$1,560	$1,788	2,104
Total R&D direct cost accepted by Government under provision of IR&D program	1,199	1,365	1,517
IR&D reimbursed by DOD	598	643	708
IR&D reimbursed by NASA	46	49	54
Total IR&D reimbursed by DOD & NASA	644	692	762

SOURCE: Annual Defense Contract Audit Agency (DCAA) Report, "Summary of IR&D and B&P Costs Incurred by Major Defense Contractors, and NASA, unpublished data.

Tax Incentives for R&D

The Federal Government also provides significant indirect support to R&D through tax law provisions that provide incentives for private investment in R&D. Measurement of the impact of any such incentive involves some difficult methodological problems. The effects of a particular incentive are difficult or even impossible to disentangle from the other factors leading to industry decisions to spend money on R&D.[19] To understand more fully the impact of the special Federal tax treatment of R&D would require information from industry decisionmakers to ascertain the degree to which tax considerations have affected their R&D investment decisions. There would still be the difficult task of quantifying the amounts of R&D expenditures to be ascribed to the special tax treatment of R&D.

Estimates are available, however, of the impact on Federal revenues of various preferential features of the Federal tax laws, including the provisions that give preferential treatment to R&D. These estimates are known as "tax expenditures." The Congressional Budget Act of 1974 (P.L. 93-344) requires a listing of estimated tax expenditures in the President's annual budget.[20]

Tax expenditures are defined as revenue losses attributable to the provisions of the Federal tax laws which allow a special exclusion, exemption, or deduction from gross income or which provide a special credit, a preferential rate of tax, or a deferral of tax liability. The requirement that estimates of such tax expenditures be included in the annual budget stems from congressional acceptance in the 1974 Budget Act of the view that preferential tax treatments, i.e., tax expenditures, are one of the means whereby the Federal Government pursues public policy objectives. In many cases, tax expenditures can be viewed as alternatives to direct budget outlays. The concept behind this process is that withholding or reducing the tax burden may have the same effect as a direct Federal payment.

Tax expenditures can be estimated only in relation to some assumed "normal structure" of taxation taken as a base. The tax expenditures attributed to a particular special provision are calculated as the net difference between Federal revenues that would be collected under the normal structure and those collected under the existing special provision.

The special tax provision most directly affecting R&D is the one that allows businesses to deduct all R&D expenditures in the year in which they are incurred, rather than amortize them over several years, as is required for capital expenditures. The

[18] Public Law 91-441 which governs IR&D costs requires that for such costs to be allowable, contractors with IR&D and B&P costs exceeding $2 million must enter into an advance agreement with the Government on a dollar ceiling for the level of company IR&D that the Government will accept for inclusion in indirect costs. The available overall statistics on IR&D presented here cover only contractors exceeding the $2 million threshold requirement of P.L. 91-441. At present, it is understood that about 100 contractors, comprising some 340 profit centers, meet this criterion. Contractors with less than $2 million of IR&D and B&P costs may be reimbursed for costs the auditors consider reasonable without going through all the procedures required of major contractors.

[19] For a recent summary of issues relating to tax policy and industry, see *The Impact of Tax and Financial Regulatory Policies on Industrial Innovation* (Washington, D.C.: The National Research Council, National Academy of Sciences, 1980), and preliminary papers from a colloquium on Tax Policy and Investment in Innovation held by the Division of Policy Research and Analysis, National Science Foundation, on April 24, 1981 in Washington, D.C.

[20] For the FY 1981 budget, this listing is presented and discussed in "Special Analysis G" in the Special Analysis volume of the Budget of the United States Government, Fiscal Year 1981.

estimates of the revenue losses attributable to this provision made by the Treasury Department are projected to reach nearly $2 billion in fiscal year 1981 (see table 2-5).

Table 2-5. Estimated tax expenditures produced through corporate R&D activities (Millions of dollars)

Year	Totals
1978	$1,388
1979	1,525
1980[1]	1,795
1981[1]	1,970

[1]Forecast.

SOURCE: *Special Analysis of the Budget of the United States Government*, Fiscal Years 1980 and 1981.

To what extent can these figures be taken as a measure of indirect Federal support of R&D? At the outset, it must be clearly understood that they are not a direct measure of expenditures for R&D or of R&D activity. They are the difference in the taxes that would be paid to the Government if the present tax allowance for R&D were not in place. What the figures provide is an indicator of the revenues the Federal Government is willing to forego if capital investment takes the form of R&D rather than other forms such as plant, equipment, etc. Thus, it might be said that the $2 billion in revenue losses in 1981 represents an additional R&D "cost" to the Federal Government that is equal to about 5 percent of the FY 1981 budget for R&D and 13 percent of the portion likely to go to industry.

Two caveats are especially important. First, there is no way of knowing how much of the R&D receiving special tax treatment would have been performed even without such benefit. In other words, it is not known to what extent the tax incentive was necessary to stimulate R&D activity. Second, the tax expenditure data shown here implicitly assume a trade-off between R&D and other capital expenditures, but this is not necessarily the only choice that confronts company management. Indeed, it may be more likely that the choice is between R&D and profit or between R&D and operating expenses.

SUMMARY

Quantitative analyses of resources for research and development typically do not consider the indirect ways in which science and technology in the United States are supported, such as overhead payments for "independent research and development" made primarily by NASA and DOD to their contractors and preferential tax treatment for certain corporate R&D expenditures. It is not possible to quantify the amount of all such indirect contributions. However, in order to see more clearly the full range of resources used to support U.S. science and technology and to understand better the interaction among the contributors to R&D, it is useful to review the support mechanisms that are sometimes overlooked when only budget allocations to R&D are studied. The picture which emerges from examination of two of the most prominent indirect support mechanisms shows substantial support of science and technology.

Chapter 3
Resources for Basic Research

Resources for Basic Research

HIGHLIGHTS

- National levels of basic research activity, measured by funding for basic research, have risen continually since the mid-1970's, although the rate of increase declined somewhat in 1980 and 1981. Measured in constant dollars, basic research expenditures grew at an average annual rate of 5.6 percent from 1976 to 1979. This growth was primarily due to the Federal Government's increase in its support for basic science. (See p. 73.)

- Currently, half of all U.S. basic research is performed at universities and colleges, where total basic research expenditures have been increasing since the mid-1970's. By 1981, it is projected that colleges and universities will conduct about 13 percent more basic research than they did in 1975, measured in constant dollars (See p. 74-77.)

- Industrial basic research is on the rise again. By 1981, industry—which performs about 18 percent of U.S. basic research—is expected to spend at a basic research level about 37 percent more than in 1975, measured in constant dollars. For the most part, this increase reflects the larger share of industrial research being supported by the Federal Government, especially that related to energy research (See p. 74.)

- Federal agencies have continued to support basic research as an important means of achieving their overall goals. In 1981, 14 percent of all agencies' R&D obligations were in basic research; this proportion has remained relatively stable over the last decade, even though the total constant dollar level of Federal basic research funding increased by about 27 percent. Among the major R&D agencies, the proportion of resources committed to basic research has ranged from 3 percent for DOD to 93 percent for NSF in the last several years. (See pp. 79-82.)

- Federal support for basic research in life sciences has grown markedly between 1963 to 1981, compared to other fields of science. Obligations in current dollars have grown more than fivefold over this period, versus a threefold increase in the physical sciences. (See pp. 79-82.)

- There is a growing concern that research resources available to scientists are being affected more than ever before by administrative requirements that draw on available time and money. Studies indicate that between 10 and 30 percent of a scientist's typical workweek may be accounted for by administrative requirements imposed due to institutional or governmental needs. (See pp. 83-85.)

Basic research, which plays a special role in the overall R&D process, represents the principal mode for developing the knowledge base necessary for future scientific and technological breakthroughs. These, in turn, frequently lead to significant economic benefits and improvements in social welfare. Within the academic sector, basic research also serves an important function in the education of graduate students. This chapter deals with the national resources provided for the conduct of basic research. Principal input resources refer to available funds and numbers and quality of personnel employed. The primary input indicator is available funds. Administrative responsibilities that are perceived to have an increasing effect on the available time of scientists for the conduct of basic research, are also discussed. Another chapter of this report[1] deals with the substantial human resources involved in basic research activities. The chapter entitled "International Indicators of Science and Technology" provides comparisons of U.S. R&D activities to those of other countries.

Although case studies show that the economic and social benefits from basic research projects are substantial,[2] it is still impossible to quantify them precisely in an aggregated fashion or to measure exactly other outputs of basic research, such as increases in knowledge and the scientific exchange

[1] See the Science and Engineering Personnel chapter for a detailed discussion of scientists engaged primarily in basic research.

[2] Information regarding specific discoveries in basic science that have had major, long-term effects on society appears in Eugene H. Kone and Helene J. Jordan (eds.), *The Greatest Adventure* (New York: The Rockefeller University Press, 1974); *Technology in Retrospect and Critical Events in Science (TRACES)* (Chicago: Illinois Institute of Technology Research Institute, 1968); *How Basic Research Reaps Unexpected Rewards*, National Science Foundation, 1980.

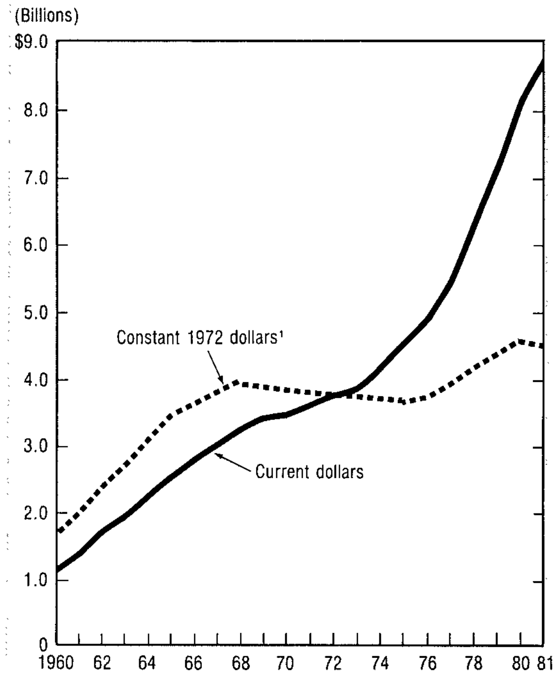
of ideas. Furthermore, many of the impacts from basic research findings are obscured by other factors. The indicators discussed in this chapter have a number of limitations. They do not cover the substantive but unquantifiable aspects of basic research, such as advances in knowledge achieved in the various scientific disciplines.[3] Also, there is presently no accurate way to measure the effectiveness or productivity of basic research activity, as the available output indicators are incomplete and the interaction between inputs and outputs is not completely understood.

There are also limitations to the data used. For example, there is not always a clear distinction between "basic" and "applied" research. A particular research effort may be identified as "basic" or "applied" depending on whether the classification is made by the research sponsor, by the performing organization, or by the individual performing the work.[4] In spite of this, definitions provided when data are gathered have been comparable over time, and interviews of survey respondents show that interpretations, while varied, seem to be fairly consistent over time. Thus, the trends presented still serve as reasonable measures of change.

NATIONAL RESOURCES FOR BASIC RESEARCH

National spending on basic research amounted to an estimated $9 billion in 1981, twice the 1975 level. Because inflation can have significant impact on the actual level of basic research activity, it is more useful to examine trends in basic research funding in terms of constant dollars,[5] which can be used as a surrogate for activity.

Figure 3-1
Basic research expenditures



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Estimates are shown for 1979-81.
REFERENCE: Appendix table 3-1.

Science Indicators—1980

In terms of constant dollars, the mid-1970's marked the beginning of a period of renewed support for U.S. science and the end of a decline in basic research expenditures that started in 1969. From 1975 through 1979, national basic research spending showed steady growth that averaged 4.4 percent annually in real terms (see figure 3-1). This exceeded the average increase for all Federal budget outlays over the same period of 3.4 percent per year and equaled the 4.7 percent constant-dollar growth per year experienced by the GNP. The Federal Government is the primary supplier of funds for basic research, providing 69 percent of its total support in 1979.

Since 1977, Federal budgets for each year have called for real growth in basic research support. This is the primary factor in the increases realized in total U.S. basic research expenditures in recent years. Over the 1975-79 period, the growth in real Federal basic research spending has averaged 4.8 percent annually. It is estimated that real growth in basic research spending beyond the 1979 level will continue in 1980 and level off or decline slightly in 1981.

[3]For illustrations of specific scientific breakthroughs, see the chapter in this report entitled "Advances in Science"; *Science*, vol. 209 (July 4, 1980), pp. 64-191.

[4]See, for example, C.E. Falk, "An Operational, Policy-Oriented Research Categorization Scheme," *Research Policy*, vol. 2 (1973), pp. 186-202; *Categories of Scientific Research*, a compendium of papers presented at a National Science Foundation seminar held in Washington, D.C., on December 8, 1979.

[5]The GNP implicit price deflator, which is prepared on a quarterly basis, has been used to create a fiscal-year as well as a calendar-year deflator. Constant-dollar figures presented throughout this report are created by applying fiscal-year deflators to performer data reported by the Federal Government, by universities and colleges and their associated FFRDC's, and by calendar-year deflators to data from the industrial sector and nonprofit institutions. See appendix table 2-1 for the actual deflators used. Obligations represent the amounts for orders placed, contracts awarded, professional services received, and similar liabilities incurred during a given period, regardless of when the funds were appropriated. Expenditures (outlays) represent amounts for checks issued and cash payments made during a given period, regardless of when the funds were appropriated.

Sources of Funds for Basic Research

As stated previously, some 69 percent of the funds for basic research are provided by the Federal Government, which has assumed responsibility for supporting basic science as a means of producing the knowledge base for future technological and economic growth and assuring that fundamental research is conducted in areas related to its own as well as to national needs. Through Federal support, the Nation can continue to maintain strong capabilities in critical areas such as national defense and health. Strong Federal involvement also occurs because the economic gains from pure science are frequently long term and do not necessarily benefit the sponsor of the research for many years, if ever. Consequently, because the industrial sector primarily stresses relatively short-term returns on its investments, it tends to place less emphasis on basic research[6] and allocates most of its resources in more applied areas and in development. Universities cannot place large amounts of their own funds in basic research because of limited financial resources.[7]

In constant dollars, Federal support for basic research grew steadily throughout the 1960's, partly because of major R&D initiatives in space, health, energy, and a steady Federal commitment to the basic research programs of the National Science Foundation. However, Federal constant-dollar basic research funding declined steadily from the late 1960's through the mid-1970's, falling at an average annual rate of about 2.0 percent in the period from 1969 to 1975 (see figure 3-2). These decreases occurred at a time of general cutbacks in Federal defense and space programs. In 1976, the Federal Government expanded its support of basic science and by 1980 had increased its constant-dollar funding by 22 percent over the 1976 level, an average annual increase of about 5.1 percent. Estimates for 1981 indicate a slight decline from the 1980 level, reflecting budget decisions designed to deal with the growing Federal deficit.

The proportion of Federal R&D funds allocated to basic research has increased steadily each year, from 14 percent in the last half of the 1960's to an estimated 19 percent in 1980. Most of the increase occurred after 1975. Allocated funds for basic research in defense, space, and health agencies have all shown increases, while the basic research proportion of the U.S. Department of Energy registered a sharp decrease, reflecting large development increases.

Support of basic research by the industrial sector has been relatively stable in constant dollars since the late 1960's. However, a significant increase in support from other sectors has reduced the fraction accounted for by this sector. The share held by industrial sources has declined from the 25-30 percent level of the early 1960's to a current level of 16 percent. As with the Federal sector, constant-dollar basic research funds from industry started increasing again in 1976, following a period of gradual decline during the late 1960's and early to mid-1970's. These increases after 1975 in large part reflected increased spending on energy programs. Industrial spending for basic research grew, in constant dollars, by 21 percent from 1975 to 1979 at an average annual rate of 5.0 percent. Additional increases, at somewhat lower rates, are projected for 1980 and 1981.

Industrial support of basic research, which in the mid-1960's accounted for 7 percent of total industry R&D support declined to 5 percent in 1970 and to 4.5 percent in 1975,[8] reflecting increased emphasis on short-term payoffs from R&D projects. Increases in energy basic research have resulted in the ratio remaining constant after 1975. In addition, since 1975 industry has had a growing interest in building its own base for future scientific and technological growth and will probably continue to increase its basic research spending.

The academic sector and nonprofit institutions each supplied a relatively small fraction of the Nation's total basic research funds—10 percent and 6 percent, respectively, in 1979. Within the university sector, approximately 75 percent of the non-Federal, separately budgeted R&D funds were spent on basic research in 1970. By 1976 this ratio had dropped to 60 percent, where it has remained. The drop in the ratio occurred at a time when the Federal Government was emphasizing support of applied research.

Performers of Basic Research

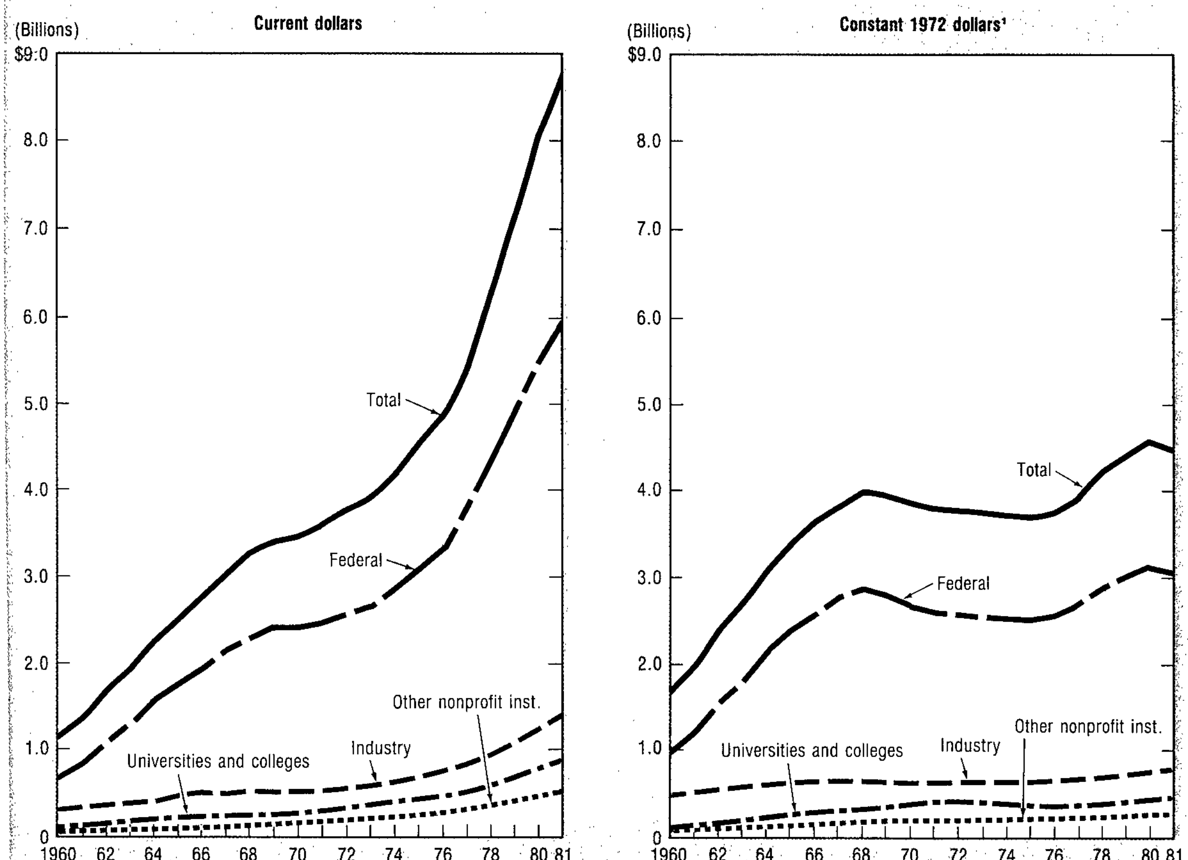
Those supplying funds for basic research support many different types of performing institutions. It is useful to examine trends in spending by these performers to understand better the institutional infrastructures used in the United States for the conduct of scientific research and to provide information useful in the assessment of the performer-distribution balance.

[6] *Special Analysis K: Budget of the United States Government, Fiscal Year 1981*, pp. 308-309.

[7] Ibid.

[8] *National Patterns of Science and Technology Resources, 1980*, National Science Foundation (NSF 80-308), pp. 29-30.

Figure 3-2
Basic research expenditures by source



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Estimates are shown for 1979-81.
REFERENCE: Appendix table 3-2.

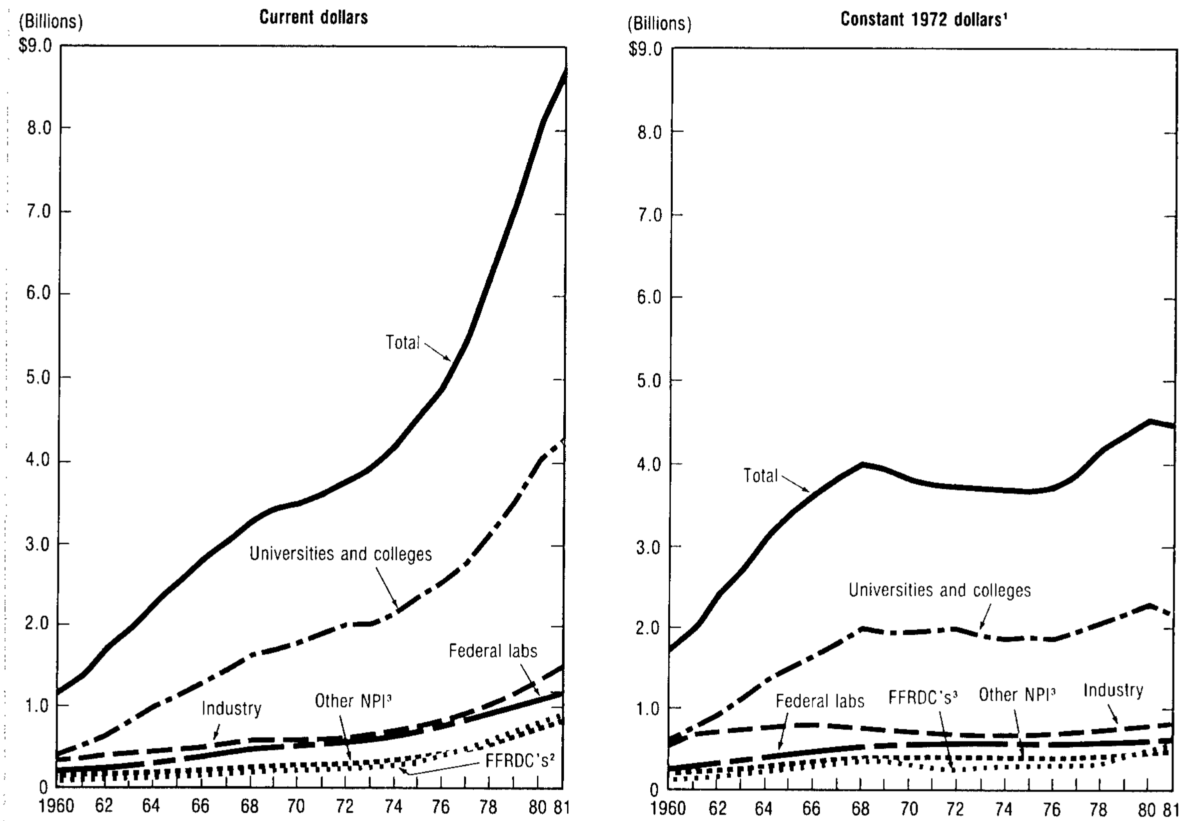
Science Indicators—1980

In terms of performance (i.e., use of funds from all sources), the academic sector accounts for the largest percentage of basic research spending. Its share of the total amounted to 50 percent in 1979, about equal to the share it has held since the late 1960's (see appendix table 3-3). Measured in constant dollars, total basic research expenditures by this sector remained relatively stable from the late 1960's through the mid-1970's and have been increasing since (see figure 3-3). These recent increases are directly attributable to the Federal Government's increased support of basic research.

Federal intramural laboratories and industry each account for about 15 percent of all basic research expenditures in recent years. Federal laboratories, however, place about 15 percent of their total intramural R&D expenditures into basic research, while industry places less than 5 percent. In terms of constant dollars, basic research expenditures in both sectors have followed the same general trends—decreases from the late 1960's through the mid-1970's of about 10 percent for industry and 20 percent for Federal intramural laboratories, and increases of the same magnitude since.

Over the last two decades, significant changes have taken place in the share of basic research activity (measured by expenditures) performed in industry and academia. In 1960, the university and college sector accounted for 36 percent of all basic research spending in the Nation, while industrial laboratories accounted for 32 percent. By 1970, the university share had increased to 51 percent, and the industry share had dropped to 17 percent, approximately their present levels. Increased Federal support of basic research during that time was a contributing factor. From 1960 to 1970, Federal

Figure 3-3
Basic research expenditures by performer



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
²Federally funded research and development centers administered by universities.
³Other nonprofit institutions.
NOTE: Estimates are shown for 1979-81.
REFERENCE: Appendix table 3-3.

Science Indicators—1980

and non-Federal support of basic research in universities increased, in constant dollars, at average annual rates of approximately 12.7 percent and 11.0 percent, respectively.

By the mid-1960's, Federal support of basic research spending in industry, as measured in constant dollars, had begun to decrease. Between 1965 and 1969, Federal basic research support to industry decreased at an average annual rate of about 7.5 percent,[9] reflecting cutbacks in defense and space programs. At the same time, industry was emphasizing short-term payoffs in its R&D efforts and had begun to stress applied research and development programs.[10] Since the late 1960's, the shares of total basic research spending by universities and by industry have remained relatively stable.

The trends in basic research expenditures by performer have been paralleled by trends in numbers of personnel engaged in basic research activities. From 1974 to 1978, the number of employed S/E's primarily engaged in basic research rose 31 percent.[11]

[9] *National Patterns of Science and Technology Resources, 1980*, p. 26.

[10] For a more complete discussion of the relationships between industry and universities and colleges, see the chapter in this report entitled "Industrial R&D and Technological Progress." See also, Edward E. David, Jr., "Industrial Research in America: Challenge of a New Synthesis," *Science*, vol. 209 (July 4, 1980), pp. 133-139, for a managerial discussion of industrial R&D.

[11] *U.S. Scientists and Engineers, 1978*, National Science Foundation (NSF 80-304), p. 5.

In 1978, universities and colleges accounted for over 42 percent of the Nation's basic research S/E's.[12] Approximately 70 percent of doctoral-level basic research S/E's were employed in universities and colleges in 1979, with fewer being employed in industry and Federal laboratories.[13]

One-third of all doctoral scientists and engineers engaged in R&D activities are primarily employed on basic research projects. In the academic sector, the fraction of doctoral S/E's engaged in basic research was 60 percent in 1979, compared to 28 percent in Federal laboratories and 9 percent in industry.

LITERATURE OUTPUT OF U.S. BASIC RESEARCH

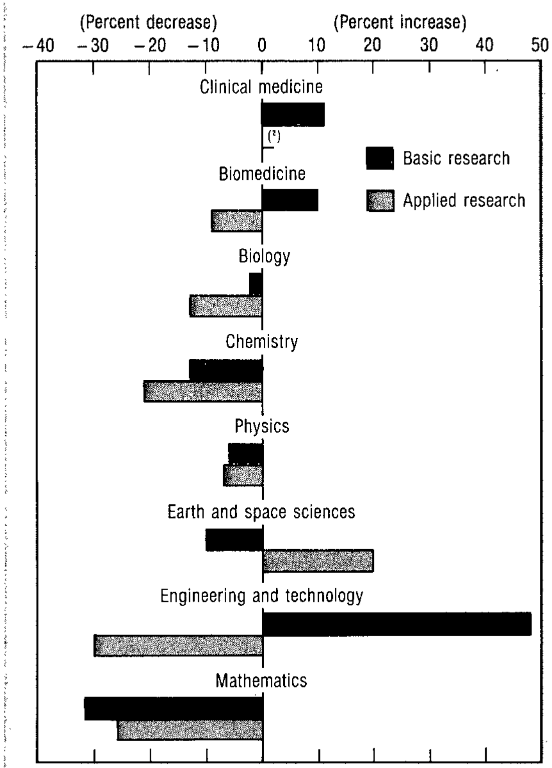
As noted previously, basic research measured in constant dollars has increased substantially over the 1975-79 period, particularly during the last few years. However, it is not yet clear what impact such funding patterns may have on the output of basic research as measured by publications produced, as there is no model to define such relationships. In addition, the interval between the performance of a research project and its publication in scientific or technical literature can vary widely from field to field; intervals of 2 to 4 years are not uncommon. Therefore, even if changes in research support were systematically linked to numbers of publications produced, the available literature data base may not yet reflect the relatively recent changes in funding patterns.

Figure 3-4 shows the changes in the numbers of basic U.S. research articles over the 1973-to-1979 period, with changes in the number of applied research articles for comparison. The substantial growth in engineering and technology articles (up 48 percent) was accompanied by a large decline in applied research articles (see appendix table 3-4.)

These divergent trends may reflect modifications in editorial policy within the fixed set of journals or the changing quality of and interest for engineering basic research results. To a lesser extent, the field of biomedicine also experienced this type of change in the scientific literature from this data base. The reverse pattern occurred in the earth and space sciences, in which basic research articles declined 10 percent while papers reporting applied research results increased 20 percent.

Figure 3-4

Percent changes in the number of scientific and technical articles[1] by U.S. authors by field and character of research: 1973 to 1979



[1]Based on about 100,000 of the articles, notes and reviews per year by U.S. authors in over 2,100 of the influential journals on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2]Less than 0.5 percent.

NOTE: See appendix table 3-5 for examples of the more basic and the more applied journals.

REFERENCE: Appendix table 3-4. Science Indicators — 1980

The greatest decrease in the number of basic research articles occurred in mathematics (32 percent), although applied mathematics articles dropped nearly as much (26 percent), in just this 6-year period. Chemistry and physics also saw losses in the number of both basic and applied research articles, though more concern may be warranted for chemistry where the decreases were 13 and 21 percent, respectively.

Basic research publications within the several U.S. research-performing sectors seem to have different patterns of growth (see appendix table 3-6). In universities and colleges, for example, the fastest growing basic research field (as measured by articles) was engineering and technology (up 43 percent), while the greatest decrease from 1973 to 1979 occurred in mathematics (down 32 percent). In comparison, Federal Government S/E's produced their greatest increases (16 percent) in biology articles,

[12]Ibid., p. 51.

[13]*Characteristics of Doctoral Scientists and Engineers in the United States, 1979,* National Science Foundation (NSF 80-823), p. 33.

while the greatest decline (28 percent) took place in physics.[14] Industry basic research articles increased in engineering and technology over this 6-year period as they did in the academic sector, but industrial clinical medicine basic research articles dropped 23 percent.

Universities and colleges have accounted for the greatest share of the basic research articles throughout the period from 1973 to 1979, varying by field from 35 to 93 percent of the total for all sectors (see appendix table 3-6). In this same period, there has been a slight trend toward even greater concentration in this sector, especially for clinical medicine, biology, and the earth and space sciences, where the share accounted for by the academic sector was 3 to 4 percentage points greater in 1979 than it had been just 6 years earlier.

It might be thought that literature data are less useful as indicators for industry, given the lower incentives and even deterrents to publishing industrial basic research results in the open literature. It is likely that a smaller proportion of the total basic research output of industry may be captured by this large sample of influential journals. Nonetheless, this possible underrepresentation rate may have been constant over time, so that trends are not affected.

One way to measure the extent to which basic research in one sector is used by or is familiar to S/E's in other sectors is to show the level of joint authorship across the different sectors. This indicator of cooperative basic research, which was described more fully in the previous chapter, varies by sector and by field.[15] As can be seen in table 3-1, the Federal Government is involved to a higher degree in cooperative basic research than are the other two sectors, according to this indicator. Industry seems to have moved the most rapidly toward this mode of research, particularly in the three life science fields. The Federal Government articles in physics and in biology shifted toward the cooperative mode more than other fields in that sector, while the earth and space sciences experienced the greatest increases in the academic sector.

[14] Although the number of basic research articles produced by this sector rose 21 percent in engineering and dropped 41 percent in mathematics, these rates of change are uncertain since in both cases there were less than 100 articles in 1973 on which to base the percentage changes.

[15] See the chapter on "Industrial R&D and Technological Progress" for the use of this indicator to describe trends in industry-university research interaction.

Table 3-1. Cooperative basic research research index[1] by field for selected R&D-performing sectors: 1973 and 1979

Field[2]	Colleges and universities			Federal Government			Industry		
	1973	1979	Increase in index	1973	1979	Increase in index	1973	1979	Increase in index
Clinical medicine	50	54	4	60	61	1	29	41	12
Biomedicine	38	44	6	48	56	8	35	46	11
Biology	28	35	7	36	46	10	32	49	17
Chemistry	23	29	6	28	37	9	18	21	3
Physics	37	44	7	28	42	14	24	32	8
Earth and space sciences	37	47	10	44	53	9	49	58	9
Engineering and technology	37	39	2	33	41	8	26	28	2
Mathematics	23	28	5	26	35	9	39	46	7

[1] This index represents the number of all basic research articles written by authors at a given organization with those from another organization, as a percent of all basic research articles from a given sector.

[2] See appendix table 1-13 for the subfields included in these fields.

REFERENCE: Appendix table 3-7.

BASIC RESEARCH—THE ROLE OF FEDERAL AGENCIES

Federal funds for basic research are distributed throughout the Nation according to the scientific objectives and needs of the mission agencies.[16] In addition, the National Science Foundation has a broad mandate to support basic research in the United States and to balance this support across all scientific disciplines.

The following discussion of basic research support by various Federal agencies is intended to illuminate the following questions: Which agencies are primarily responsible for basic research support? How has this support affected various fields of science? Have there been significant shifts in agencies' support over time? In and of themselves, the data that follow cannot fully answer all of these questions. However, information showing basic research priorities of the Federal Government can frequently point toward emerging areas, such as new thrusts in areas of energy technology that are likely to be the focus of more R&D support in years ahead.

In 1977, total Federal agency support for basic research increased, in constant dollars, following a period of decline throughout most of the early 1970's. When examined by individual agency, however, the trends in constant-dollar support vary markedly (see figure 3-5). Through 1979, only the two largest basic research-supporting agencies—the U.S. Department of Health and Human Services (DHHS) and NSF—have shown a general trend of year-to-year increases in basic research support since the 1960's. These two agencies account for about 55 percent of the Federal basic research total. In terms of fields of support, the life sciences receive about 44 percent of the Federal basic research total, and the physical sciences receive 25 percent (see figure 3-6.)

Over the more recent period from 1977 through the estimated 1981 obligation level, the agency registering the largest growth in constant dollars for basic research was DOD. However, DOD accounts for only about 12 percent of the Federal basic research total. The areas of research singled out for significant attention, which account for the increase in obligations by this agency, are mathematics and the physical sciences. The other agencies showing substantial growth since 1977 are the U.S. Department of Agriculture (USDA) and DHHS—advancing 15 and 22 percent respectively. These two agencies account for 6 percent and 37 percent, respectively, of the Federal basic research total. Basic research support in both agencies is concentrated in the life sciences. However, estimated 1981 obligations for DHHS are about 3 percent lower, in real terms, than the peak 1980 level.

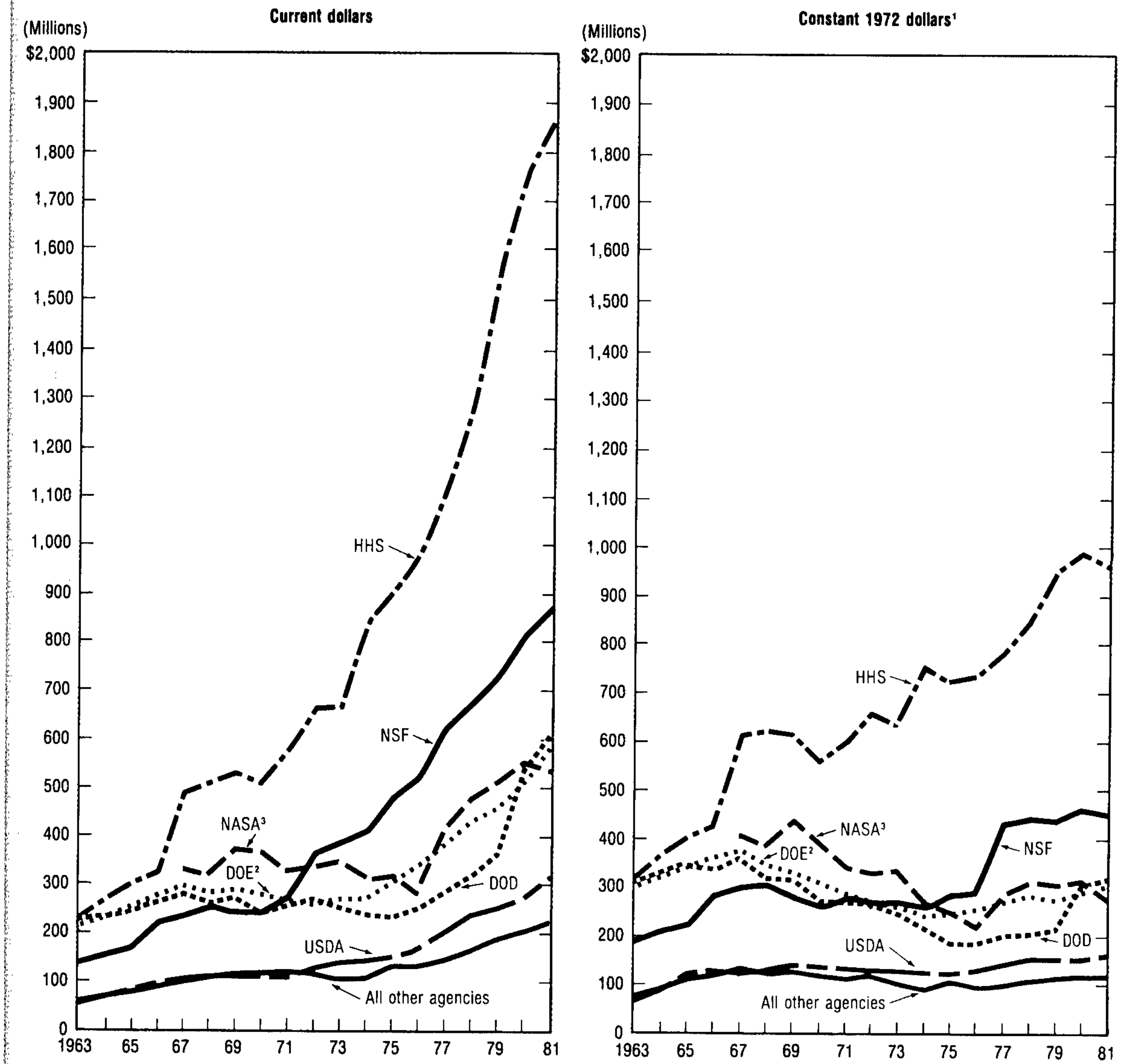
The U.S. Department of Energy (DOE) will account for about 12 percent of Federal basic research support in 1981. Its basic research obligations have grown 12 percent since 1977 in real terms, with major increases in the support of basic research in high energy and nuclear physics, materials sciences, chemicals sciences, and advanced energy concepts not yet mature enough for funding in the applied research or development areas. Basic research obligations by NASA have fallen by 5 percent in real terms in the 1977-81 period while development activities have been emphasized in recent years. NSF obligations have shown moderate growth, advancing basic research support a total of 3 percent in real terms over this period, largely in the natural sciences and engineering.

These six agencies—DHHS, NSF, DOD, DOE, NASA, and USDA—account for 95 percent of the Federal basic research support in 1981. The largest share is found at DHHS, with an estimated 32 percent of the basic research total. Over 80 percent of this agency's 1981 basic research funds are devoted to the National Institutes of Health (NIH) for the purpose of advancing the Nation's capabilities for the prevention, diagnosis, and treatment of disease. The National Science Foundation ranks second in basic research support, with 15 percent of the 1981 total. The NSF mandate is to support the advancement of research, with emphasis on basic research, and to strengthen the Nation's capabilities in all scientific disciplines. Basic research obligations by NASA and DOE account for 9 percent and 10 percent of the total in 1981; USDA and DOD account for 5 percent and 10 percent, respectively.

The relative importance an agency attaches to basic research rather than to applied research or development may reflect the agency's perception of the potential of a particular knowledge base to help it fulfill its mission or to contribute to national needs in areas closely related to its mission. NSF allocates most of its R&D resources to basic research, more than 90 percent each year since 1977 (see figure 3-7). Applied research programs were introduced to NSF throughout the late 1960's and early 1970's, and then some were transferred in the mid-1970's to the Energy Research and Development Administration (now subsumed under DOE). Although NSF traditionally has devoted most of its R&D funds to basic research, in recent years it

[16] For a detailed treatment of the types of basic research programs undertaken by these agencies and other aspects of this general topic, see the 1978 annual report of the National Science Board, *Basic Research in the Mission Agencies: Agency Perspectives on the Conduct and Support of Basic Research* (NSB 78-1).

Figure 3-5
Federal obligations for basic research by agency



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

[2]Data for 1963-73 represent obligations by the Atomic Energy Commission; 1974-76 data represent obligations by the Energy Research and Development Administration; 1977-79 data represent obligations by the Department of Energy.

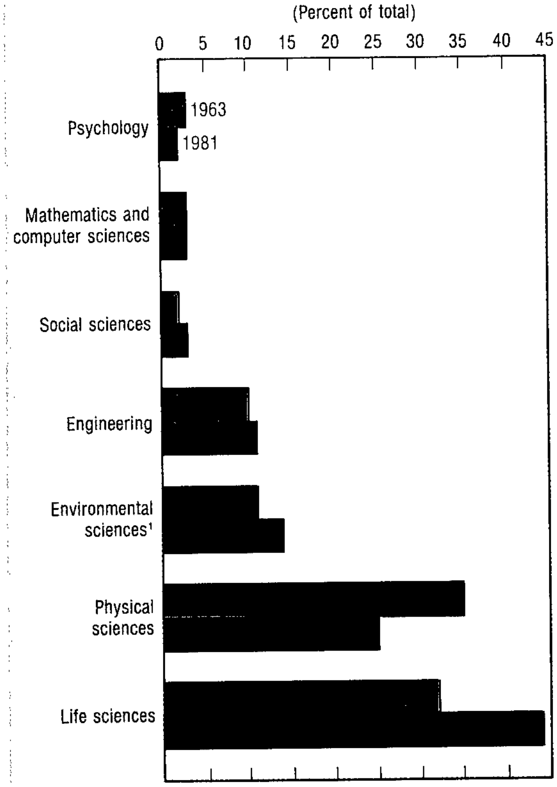
[3]Comparable data for NASA are not available for most years prior to 1967.

NOTE: Estimates are shown for 1980 and 1981.

REFERENCE: Appendix table 3-8

Science Indicators — 1980

Figure 3-6
Distribution of federal basic research obligations by major field of science



[1]Includes atmospheric sciences, geological sciences and oceanography.

REFERENCE: Appendix tables 3-10 and 3-11

Science Indicators — 1980

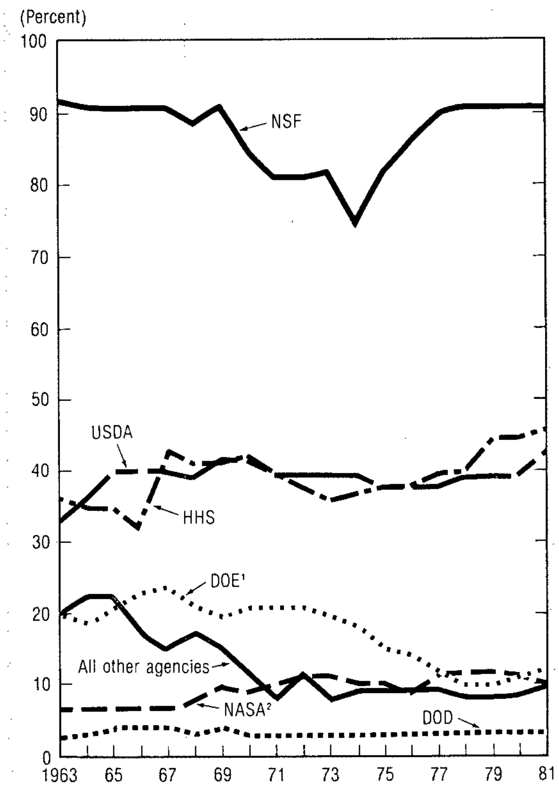
has increased the proportion of its funds that supports applied research. About 88 percent of NSF's basic research funds are awarded annually to researchers in universities and colleges and their associated FFRDC's.[17]

DHHS and USDA devote 46 and 41 percent, respectively, of their R&D funds to basic research. With its charter to advance the Nation's capabilities in biomedical research, DHHS has been funding basic research programs in the areas of disease prevention, nutrition, genetics, etc. About two-thirds of this research is conducted at universities and colleges and their affiliated FFRDC's, and an additional 20 percent at intramural laboratories, primarily the National Institutes of Health. The USDA funds basic research efforts through its intramural agricultural research programs and State cooperative experiment stations on plant and animal production; soil, water, and air resources; human nutrition, and other areas. In addition, USDA supports some basic research through an extramural research grant program.

DOD, NASA, and DOE each devote small portions of their R&D funds to the support of basic research because their defense, space, and energy missions are heavily developmental in nature.

The basic research funding patterns of the various agencies are concentrated in different fields due to the different missions of the agencies. As a result, the following field-of-science distribution patterns have occurred. Since 1963, the life sciences and the physical sciences together have accounted for about

Figure 3-7
Federal obligations for basic research as a percent of each agency's R&D obligations by agency: 1963-81



[1]Data for years 1963-1973 are for the Atomic Energy Commission; 1974-76 are for the Energy Research and Development Administration, 1977-1979 are for the Department of Energy

[2]Comparable data for NASA are not available for most years prior to 1967

NOTE: Estimates are shown for 1980 and 1981

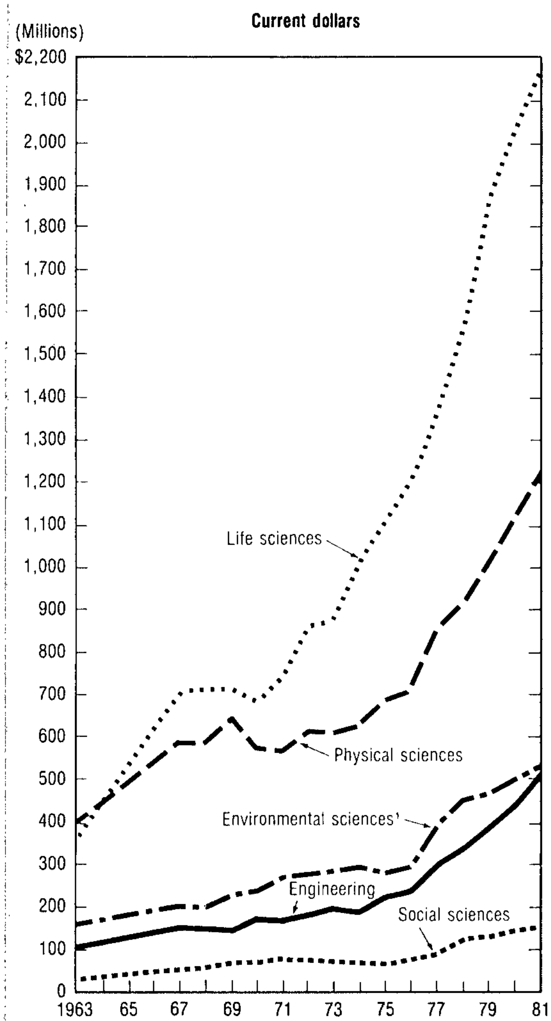
SOURCE: Appendix table 3-9

Science Indicators — 1980

[17]*Detailed Statistical Tables. Federal Funds for Research, Development, and Other Scientific Activities, Fiscal Years 1979, 1980, and 1981*, vol. 29, National Science Foundation (NSF 80-318), p. 62.

70 percent of total Federal basic research support (see figure 3-8). However, between 1963 and 1981, Federal support of basic research in the life sciences has increased more than fivefold, in current dollars. On the other hand, the physical sciences have increased considerably more slowly, about threefold (see figure 3-8). Although there are no field-specific deflators available, if the overall GNP deflator were applied to these data, it would be seen that basic research funding for the life sciences was still up sharply over this period, while that for the physical sciences remained relatively level.[18] Federal basic research funds for the life sciences, as a percent of all Federal basic research funds, have risen from 32 percent to 44 percent over this 1963-81 period, while the proportion of support for the physical sciences has dropped from 35 percent to 25 percent. However, this shift toward the life sciences occurred before the mid-1970's. The increase in life sciences basic research over this entire period reflects the growing emphasis on basic research at DHHS. Recently, NSF and DOD have initiated programs designed to stimulate basic research in the physical sciences.

Figure 3-8
Federal obligations for basic research by selected field of science



¹Includes atmospheric sciences, geological sciences and oceanography.
NOTE: Estimates are shown for 1980 and 1981
REFERENCES: Appendix tables 3-10 and 3-11 Science Indicators—1980

SUMMARY

Basic research represents the principal mode for developing the knowledge base necessary for future scientific and technological breakthroughs. By its very nature, basic research does not result in many outputs that can be quantified over a short time frame; however, the input resources provided for basic research are quantifiable. The principal input resource, of course, is the level of funding available.

National spending on basic research amounted to an estimated $9 billion in 1981, twice the 1975 level. In constant dollars, this 1975-81 growth amounted to approximately 22 percent. This followed a 7-year period in which constant-dollar basic research spending decreased by about 8 percent. The Federal Government is the primary supplier of basic research funds, providing 69 percent of the total support in 1979. The Government's support of basic research has been largely responsible for the increases in basic research funding since 1975. In addition, cutbacks in Federal defense and space programs during the late sixties and early seventies were chiefly responsible for the constant-dollar drop in total basic research funding during that time. Estimates indicate that defense basic research support will increase considerably in the early 1980's.

The Federal sector has assumed major responsibility for supporting basic science as a means of producing a future knowledge base. Federal support of basic research is estimated to have continued its constant-dollar gains in 1980 then dropped slightly in 1981.

[18] It is extremely difficult to estimate the effects of inflation on spending levels in particular fields of science, because no deflators are available which adequately account for field-specific differences in labor and capital intensity. Thus, it is difficult to show the extent to which current-dollar increases presented here represent real gains in resources available to scientists working in these fields; however, as with so many of the indicators discussed in this report, it is likely that real gains have occurred in the level of performance of basic research only in the last few years.

In terms of performance, the academic sector accounts for the largest share of national basic research spending—approximately 50 percent since the late sixties. This sector's basic research spending, in real terms, remained relatively stable from the late sixties to the mid-seventies and has been increasing since. These recent increases are directly attributable to the Federal Government's increased support for basic research.

The Federal Government's basic research funding trends vary markedly when individual agencies are examined. Between 1970 and 1979, the two largest basic research supporting agencies—DHHS and NSF—have shown a general trend of constant-dollar year-to-year increases in basic research support. Together they account for more than 55 percent of the Federal basic research total.

ADMINISTRATIVE RESPONSIBILITIES AND THE CONDUCT OF BASIC RESEARCH

The partnership between universities (as the Nation's primary performers of basic research) and their patrons has usually been discussed in terms of the level and pattern of fiscal policy toward support of basic science. Such a discussion cannot fully illuminate the less quantifiable aspects of the performer-sponsor relationship. For example, it does not address the growing concern that resources available to scientists for research are being affected more than ever before by administrative requirements that draw upon available time and money. Administrative requirements come from the Federal Government, State and local governments, and universities and colleges themselves, but it is the Federal sector that has received the most attention.

Many of the concerns regarding administrative requirements and their impact on research performance stem from increased pressures for greater accountability for public resources.[19] It is very difficult to quantify accurately the extent to which changes in administrative requirements have affected research performance. However, a number of recent efforts have contributed more quantitative information than has been available previously.

The first of these efforts[20] involved a survey in which science and engineering faculty members from the Nation's universities and 4-year colleges were asked to keep a daily log of professional activity during 1 week of a full calendar year. The survey results are based on a stratified sample of 6,385 faculty members from 20 teaching and research fields.

Overall, the respondents' average professional activity time was 46 hours per week. Science and engineering faculty reported spending 5 hours per week (11 percent) on administrative responsibilities and 11 hours (24 percent) on research (see table 3-2). Administration was defined as time spent on departmental or institutional administration, committees, and other miscellaneous institutional activities. Thus, many of the administrative tasks performed are in response to the needs of the researcher's own institution.

Of the 11 hours per week spent on research, 6 hours was for sponsored Federal research, and 3 hours for nonsponsored research (specific research projects not separately budgeted). Since the total time available for research includes time spent writing research proposals, grant or contract administration, supervision of students, and writing reports in addition to performing research, it is apparent that scientists and engineers must also commit a portion of their research time to administrative requirements of one sort or another. Unanswered by these data is the question of whether these responsibilities are more extensive or time consuming than in previous years. However, many new administrative requirements that did not exist a decade ago, such as human subjects review, biological safety certification, waste disposal monitoring, and others, have impinged on researchers' time.

Another effort[21] to measure the time scientists devote to administrative matters took the form of a case study in which interviews were conducted with a limited sample of scientists at one of the Nation's largest research universities to gather estimates of the proportion of time spent on research and research-related administrative matters. Data for research were divided according to time spent on planning, writing, and followup on research proposals; assembly of necessary research resources;

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[19] One of the most recent and extensive reports is *Accountability: Restoring the Quality of the Partnership* (Washington, D.C.: National Commission on Research, 1980). Other literature and additional bibliographic citations on the topic can be found in the following sources: Linda S. Wilson, *Government-University Relationships: The Conduct of R&D* (Washington, D.C.: National Technical Information Service); A. Carl Leopold, "The Burden of Competitive Grants," *Science*, vol. 203 (February 16, 1979), p. 607; Elmer B. Staats, "Federal Research Grants," *Science*, vol. 205 (July 6, 1979), p. 18; Saunders Mac Lane, "Total Reporting for Scientific Work," *Science*, vol. 210 (October 10, 1980), pp. 158-163.

[20] *Professional Activities of Science and Engineering Faculty in Universities and Four-Year Colleges*, Rockville, MD: Information and Communications Applications, Inc., 1980).

[21] Joseph L. McCarthy," Administrative Burdens Perceived by Basic Science Faculty," in *Papers Commissioned as Background for Science Indicators—1980*, vol. III: Administrative Responsibilities and the Conduct of Academic Basic Research, National Science Foundation, 1981.

Table 3-2. Mean hours and percent time per week spent by science and engineering faculty in professional activity: 1978-79

Activity	Hours per week	Percent of time[1]
All Activity	46	100
Instruction	18	39
Research	11	24
Federally sponsored	6	13
Nonfederally sponsored	2	4
Nonsponsored	3	8
Public service	2	4
Administration	5	11
Professional activities	2	4
Outside income production	4	8
Continuing education and professional enrichment	5	10

[1] Calculated from unrounded percentages.

NOTE: Detail may not add to total due to rounding.

SOURCE: *Professional Activities of Science and Engineering Faculty in Universities and Four-year Colleges*, Information and Communication Applications, Inc., preliminary reports.

experimentation; writing results; and other research activities. The survey sample was composed of respondents in two major categories: assistant professors who had recently begun their associations with their institutions, and full professors and department chairmen who are well established and recognized researchers in their fields. Wide generalizations are unwarranted because the sample was relatively small (n=29) and limited to one institution. However, the sample was representative of a large major U.S. research institution and the full professors sampled were all well-established and highly respected researchers.

This study shows that persons in both of the above-mentioned categories spent approximately equal fractions of total available time on research and research-related activities (see table 3-3). The amount of time spent on research-related administrative matters was substantial. Full professors reported that one-quarter of their total research time was allocated to administration; assistant professors reported spending one-third of their total research time on such matters. In this study, research-related administrative matters refer to proposal writing and assembling the necessary staff, equipment, and other support for research.

Direct comparisons between the activity-reporting study and the case study cited here are not possible due to differences in definitions of data elements and survey procedures. However, the activity-reporting study indicates that among a large sample of scientists and engineers, approximately 11 percent of all professional activity time is taken up with administrative matters. On a smaller scale, evaluation of total research time on a case-study basis shows that between one-quarter and one-third of the time available for scientific research activities was devoted to administrative matters.

The data presented above address the general issue of administrative burden and its impact on on research performance, but they do not shed much light on the nature of the administrative tasks involved or the attitudes toward them held by

Table 3-3. Estimated time devoted to research and research-related matters at a single U.S. research university, as a percent of average total research time, by type of research-related activity: 1979

	Chairmen and full professors		Assistant professors	
	Hours	Percent	Hours	Percent
Average total research and development hours per week	25	100	28	100
Research activity:				
Planning	4	17	5	17
Proposing	4	16	6	21
Assembling	2	9	3	12
Experimenting	8	31	8	29
Writing	5	20	5	18
Other	2	7	1	4

NOTE: Detail does not add to total because of rounding.

SOURCE: Joseph L. McCarthy, "Administrative Burdens Perceived by Basic Science Faculty," a paper commissioned by the Science Indicators Unit, National Science Foundation, 1980.

the principals in the Government/university partnership. The National Commission on Research has published several reports that discuss different views on the objectives of the association between the Federal Government and the academic community and the conditions under which the two sectors collaborate.[22]

The Commission's report on accountability identifies five specific issues related to the Government sector. They are stewardship, intervention, resource allocation, diversion, and public confidence. Specific issues pertaining to the universities are criticism for poor management, reduction of research, reduced flexibility, and public confidence. Although the accountability issue is discussed in widely varied terms, the report observes that the main theme may be summarized as follows: "The problem for the *public* is to ensure that the best research is produced and that public funds are not wasted or abused. The problem for the *Government* is to attain fully its program and purpose and to fulfill its stewardship responsibilities. The problems for *universities* are to conduct research well, to avoid diversion of resources to meet unnecessary administrative requirements, and to protect the integrity of their operations. Both the universities and the Government seek to maintain public confidence, because support for their activities depends on it."[23]

SUMMARY

The research partnership that has been forged between universities and governmental organizations has been a major strength of U.S. science. There is, however, growing concern about the effects on the partnership of increasing administrative responsibilities that may divert time available for research.

Although quantitative information related to this issue is very difficult to obtain, one large-scale survey shows that scientists and engineers report spending approximately 5 hours per week, or 11 percent of their professional activity time, engaged in administrative matters. A small case study conducted at a major research university suggests that between one-quarter and one-third of available research time may be allocated for research-related administrative tasks. Other studies of a less quantitative nature support the concern over the impact of administrative matters on research, but at the same time recognize the need for sufficient administrative procedures to account properly for the public resources provided for research.

[22] These reports, all published in 1980, are entitled *Accountability: Restoring the Quality of the Partnership; Funding Mechanisms: Balancing Objectives and Resources in University Research; and Review Processes: Assessing the Quality of Research Proposals.* Also, a number of institutional self-studies related to governmental factors affecting academic institutions were prepared for the Sloan Commission on Government and Higher Education and are discussed in the final report of the Commission.

[23] *Accountability: Restoring the Quality of the Partnership,* p. 1.

Chapter 4
Industrial R&D and Technological Progress

Industrial R&D and Technological Progress

INDICATOR HIGHLIGHTS

- Industrial constant-dollar R&D funding advanced at the rate of 5 percent per year from a low point in 1975 to 1979. In 1979, industry accounted for about 70 percent of the Nation's total R&D funds and R&D personnel. Annual increases in constant-dollar funding ranging from 4 to 5 percent are estimated for 1980 and 1981. (See pp. 91-92.)

- Private funding continues to be the mainstay of industrial R&D support. It constitutes two-thirds of the total and, unlike Federal funding, it is at its highest level historically, even in constant dollars. In addition, it is the faster-growing source—6 percent per year from 1975 to 1979 in constant dollars, more than twice the growth rate for Federal support. This rate of increase is estimated to be about the same for 1980, but to decline slightly to 4½ percent in 1981. Private expenditures are highly dependent on company resources, being closely related to both net sales for all industries performing R&D and total corporate cash flow. (See pp. 93-94).

- Federal support of industrial R&D amounted to about one-third of that effort in 1979. In the early 1960's, the Federal portion was nearly 60 percent, from which it has declined steadily to the present percentage. This funding goes mainly into areas of direct Federal responsibility, such as defense and space. To a much smaller extent, it is directed to areas of broad applicability, such as basic research. Federal funding in constant dollars increased at a rate of 3 percent per year from 1975 to 1979. Increases of 2 and 5 percent are estimated for 1980 and 1981. (See pp. 92-94.)

- Industry's share of the Nation's R&D effort is substantially concentrated in development. In 1979, 78 percent of industrial R&D funding was in development, with 19 percent going to applied research and only 3 percent to basic research. In the same year, total national R&D expenditures were 64 percent development, 22 percent applied research, and 13 percent basic research. Federal support of industrial R&D is particularly development-oriented. Thus, since 1971, the private contribution to industrial basic research has been more than three times the Federal contribution. Constant-dollar development expenditures have risen by 5 percent per year from 1975, their recent low point, to 1979. For 1980 and 1981, 4- and 5-percent increases are estimated. The pattern for applied research is similar. Constant-dollar basic research expenditures rose faster, by 6 percent per year, from 1975 to 1979. This increase may reflect a concern on the part of industry that the previous decline in industrial basic research was disadvantageous in the long run. (See pp. 94-95.)

- In terms of dollars, the aircraft and missiles industry performs the most industrial R&D, 22 percent of the total in 1979. This is also the industry that is most dependent on Federal R&D funding, with 73 percent coming from that source in 1979. However, this is the lowest share of R&D funding that the aircraft and missiles industry has received from the Government in more than 20 years. Since 1975, large increases in R&D funding have occurred in scientific and mechanical measuring instruments, motor vehicles, electronic components, paper, and nonmanufacturing. On the other hand, since 1975, very small increases or even declines, in deflated dollars, have taken place in R&D in radio and TV receiving equipment, ferrous metals and products, rubber, and textiles. (See pp. 97-99.)

- The companies that are the largest performers of company-funded R&D, constituting about 15 percent of all R&D performers, also are the largest supporters of R&D by foreign affiliated companies. In 1979, total company-supported R&D in foreign affiliates equaled about a ninth of domestic R&D support by all U.S. companies. Moreover, the rate of increase is faster for foreign expenditures. It was 16 percent per year from 1974 to 1979, more than the 11 percent increase for domestic private support. The ratio of foreign to total private support is highest for chemicals, including drugs (12 percent in 1979); motor vehicles and other transportation equipment (18 percent in 1977); and nonelectrical machinery, including computers (12 percent in 1979). These foreign expenditures have been justified in terms of the need to meet local market conditions in those countries. (See pp. 100-101.)

- Patenting data suggest a decline in the production of technical inventions by Americans, particularly by corporations, beginning about 1970. From 1971 to 1978, U.S. patenting declined by an average of 2 percent per year for all inventors, and 3 percent per year for company-employed inventors. This trend is also worldwide, with many important industrial countries showing a decline in domestic patent applications beginning in the middle or late 1960's. In the United States, the drop in constant-dollar research funding in industry from 1969 to 1975 may provide a partial explanation for the drop in patenting. Increased technological competition by foreign countries is shown by the rapid increase in foreign patenting in the United States from 1963 to 1976, at an average rate of about 15 percent per year. (See pp. 109-113.)
- Since the 1974 Arab oil embargo, the increased industrial research in energy technologies has been reflected in an increase in patenting in these technologies. In 1978, 9 percent of all patents granted in the United States were in energy technologies. A large number of these were in fossil fuels or electric power, but activity in these areas has been decreasing by an average of 2-4 percent per year since 1973. Rapid increases have occurred in new technologies such as wind, geothermal, and especially solar energy, where patenting has risen more than 90 percent per year, on the average. (See pp. 115-116.)
- Recent declines in patenting are paralleled by low rates of increase in U.S. nonfarm industrial productivity. In the manufacturing industries, labor productivity grew by 3.3 percent per year from 1957 to 1965, but the increase dropped to 2.8 percent per year from 1965 to 1973, and only 1.7 percent per year from 1973 to 1978. Manufacturing-industry productivity increased from 1978 to 1979 by 1.0 percent, but decreased from 1979 to 1980 by 0.3 percent. From 1973 to 1978, especially large productivity improvements occurred in motor vehicles and equipment (6.2 percent per year), food, textile mill products, and apparel and fabric products (all 3.9 percent per year). Many of these improvements are due to investments in capital equipment embodying new technology. The poorest performance among manufacturing industries from 1973 to 1978 was in primary metals (a drop of 2.7 percent per year) and aircraft and parts (down 1.8 percent per year). Problems with industrial productivity are attributed in part to failure to invest in the latest equipment and, in some cases, to the decline in constant-dollar R&D support after 1969. However, nontechnological influences on productivity are also important. (See pp. 120-123.)
- Industry's research output, as measured by annual published technical articles in eight fields, decreased by 21 percent from 1973 to 1979. This decrease is well above the 4-percent drop in such publications by all U.S. authors. Most of the decline in industry publishing is due to the 36-percent drop in annual applied research publications in engineering and technology. (See pp. 106-107.)
- Cooperation between industry and university researchers, as measured by joint research publications, increased from 1973 to 1979 in spite of the overall drop in industry-authored publications. The number of annual jointly authored articles increased by 9 percent over this period; by 1979 it reached 17 percent of all articles written with industry participation. The largest percentage increases were in biology (45 percent), physics (33 percent), and biomedicine (32 percent). Trends in the citing of papers written in one sector by papers written in the other suggest that industry draws on university research more than universities draw on industry. This was decidedly the case for five of eight research fields in 1973. By 1977, industry had this one-sided dependence on university publications only in chemistry and the earth and space sciences, while universities continued to depend more on industry in physics. (See pp. 106-108.)

The industrial sector is especially important in any consideration of R&D, since most of U.S. R&D is performed by industry. Industrial technology, drawing on industrial and nonindustrial R&D, provides benefits to the public in the form of new and improved products and services. In addition, the health of the entire U.S. economy is vitally dependent on the health of the industry sector. One of the principal bases of industrial strength is improving technology, promoted by investment in R&D.

In recent years, considerable attention has been given to problems in the U.S. economy related to a presumed weakening of the technological performance of U.S. industry. A whole litany of symptoms has been brought forward. For example,

overall economic growth in the 1970's is below that in the 1950's and 1960's.[1] The U.S. standard of living is no longer the highest in the world.[2] U.S. industrial productivity has failed to improve at the rate achieved in other major Western countries.[3] U.S. manufacturers' market share is shrinking both in the United States and abroad, especially in major industries like steel, automobiles, and consumer electronics. As a percent of gross national product, industrial R&D expenditures and investment in plant and equipment are declining by comparison with other major Western countries. The value of net capital stock in private business and the ratio of capital stock to employed labor are not increasing as fast as in previous years.[4]

Because of this perception that the U.S. industrial economy is in difficulty, many studies have been initiated by private industry and by the Government to identify appropriate actions in connection with innovation. Participants in these exercises agree for the most part that there is a genuine innovation problem. However, these efforts do not have the benefit of any direct measures of technological innovation and usually do not themselves generate any new data. As a result, some experts are not convinced that the existence of an innovation problem in U.S. industry has been demonstrated.[5] Further, to the extent that there is a problem, it is disputed whether it relates to the generation of new technology or to the economic environment for the development and exploitation of technology.

Thus, the problem of providing adequate measures of industrial R&D, technology, and innovation continues to exist. This chapter addresses only a part of this problem, by presenting quantitative information applicable to an important set of policy questions. The first question that the data illuminate is whether U.S. industry carries out enough R&D in the right areas. The available quantitative information most relevant to this question is in terms of the resources that industry devotes to R&D, specifically dollars and personnel. However, there are several limitations to the use of such indicators. Dollars and personnel are not exactly the same as the real R&D input—the amount and quality of work done. Also, there are other resources, such as R&D equipment, that these data on the industry sector do not capture. Finally, there is no obvious standard for determining the correct levels of resource input. Ideally, resource levels would be judged for adequacy in terms of their results or outputs, but as yet there is no quantitative way of estimating the output corresponding to a given input. In the absence of a model that would establish such links quantitatively, this chapter compares present levels of resources with past levels.[6]

Another question addressed by the data in this chapter is the impact on industrial technology of the supporting R&D efforts in universities. Again, only a few kinds of indicators are currently available, and comparison can only be made with the past because there is no accepted standard for adequate levels. Besides the transfer of resources, it is also possible to estimate the transfer of information by examining the publication of journal articles; namely, the trends in joint publication by personnel in the two sectors and in the extent to which articles from one sector cite articles written in the other.[7]

Finally, the question of most direct interest is the level and adequacy of present U.S. technology, as well as of new technology, i.e., invention and innovation. No completely adequate measures of technology now exist, although there are quantitative indicators for the technical performance of many products.[8] In this chapter, a few new indicators of this kind are presented and related to underlying technical developments. Novel technical inventions are represented by rates of patenting. In spite of well-known limitations, patent counts

[1]"The Reindustrialization of America," *Business Week*, (June 30, 1980), pp. 56-65.

[2]Standard of living is measured here in terms of per capita disposable income. The last year in which the United States was first in the world by this measure was 1972. However, the United States is still first in terms of per capita consumption.

[3]The international aspects of this problem are treated in the chapter on International Science and Technology.

[4]*America's New Beginning: A Program for Economic Recovery*, Part III: *A White House Report*, Executive Office of the President, February 1981, p. 5.

[5]*Science and Technology: Annual Report to the Congress*, National Science Foundation, 1978. The existing data on U.S. industrial innovation are summarized in Mary Ellen Mogee, *Technology and Trade: Some Indicators of the State of U.S. Industrial Innovation*, printed by the Subcommittee on Trade of the Committee on Ways and Means, U.S. House of Representatives, April 21, 1980. Much of this material is taken from previous *Science Indicators* reports.

[6]Comparison can also be made with resource levels in other countries, as in the chapter on International Science and Technology. Also, informal links with outputs are often used, as when a decline in patenting is attributed to a decline in R&D expenditure.

[7]Information transfer also occurs when "new entrants," i.e., new university graduates with scientific and technical training, are hired by industry. This type of transfer is discussed in the chapter on Scientific and Engineering Personnel.

[8]An obvious example would be the technical performance parameters, like signal-to-noise ratio, that apply to commercial sound equipment.

are an irreplaceable source of information about technical invention. The economic aspect of innovation is reflected in part in industrial productivity measures.

LEVEL OF R&D EFFORT IN INDUSTRY

The amount of R&D work performed in industry cannot be measured directly. However, it can be represented by the resources expended in that effort, i.e, money and person-hours of work. The indicators in this section thus deal with the funds expended on industrial R&D and with the numbers of professional scientists and engineers employed in this effort. Given the resources devoted to industrial R&D, questions also can be asked about the quality of these scientists and engineers and whether they are being used effectively. These further questions cannot be addressed very thoroughly with indicators of the kind presented in this chapter.[9]

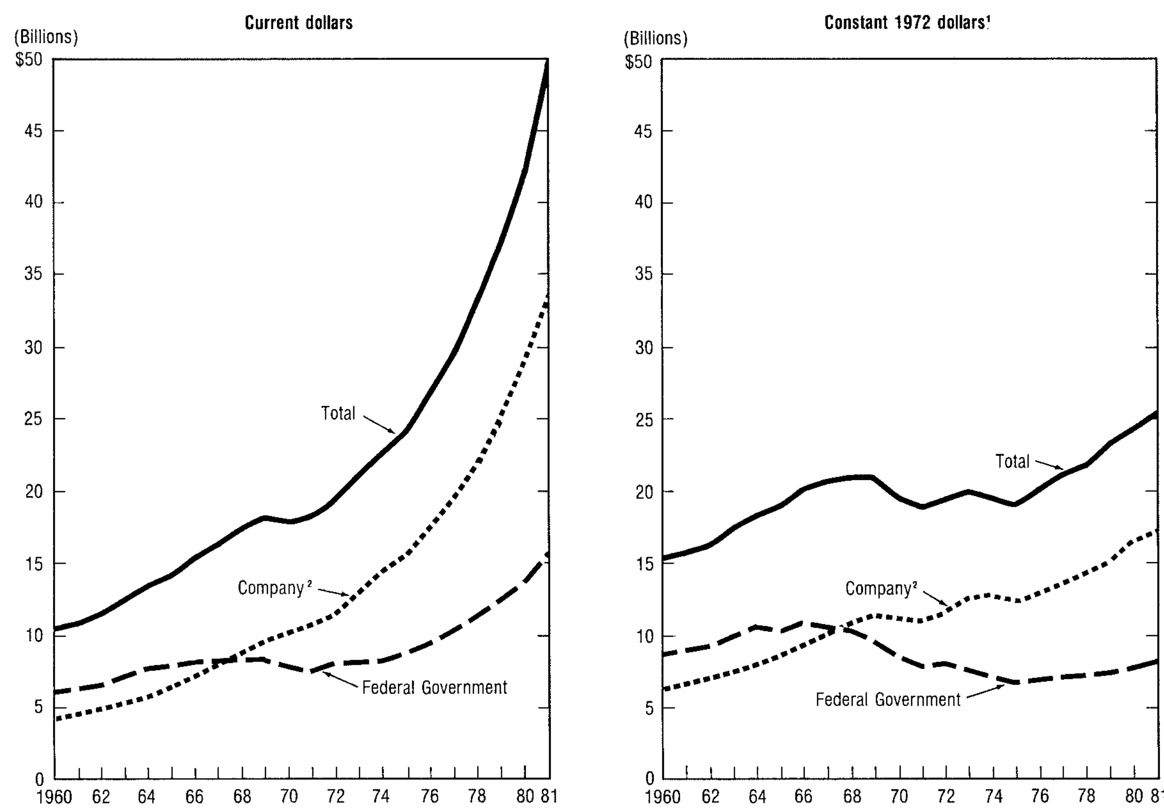
Total Resources for Industrial R&D

The importance of industry in the Nation's total R&D effort is suggested by the fact that $37.6 billion, from all sources, was spent on industrial R&D in 1979 (see figure 4-1). This was 69 percent of the U.S. R&D effort in that year.[10] In industry, there was a 13.4-percent increase in expenditures over the previous year, well above the 8.4-percent average annual rate of increase since the dip in industrial R&D funding that occurred in 1970. By

[9]See the chapter on Scientific and Engineering Personnel for some indicators of the quality of such personnel.

[10]National Science Foundation, preliminary data.

Figure 4-1
Expenditures for industrial R&D by source of funds



[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
[2]Includes all sources other than the Federal Government.
NOTE: Preliminary data are shown for 1978-80 and estimates for 1981.
REFERENCE: Appendix table 4-1.

Science Indicators—1980

comparison, manufacturing industry spent $55.2 billion for new plant and equipment in 1978.[11] Thus, R&D is an important industrial expense. In terms of the overall scale of company activities, R&D expenditures were 3.1 percent of corporate net sales in 1979. While this ratio has remained steady since 1974, it was as high as 4.6 percent in 1964 and declined gradually thereafter.[12] Figure 4-1 shows that continued increases in R&D spending of 14 and 15 percent per year are projected for 1980 and 1981.[13]

If allowance is made for inflation,[14] total industrial R&D expenditures dipped in 1969, 1970, and 1971 and also in 1974 and 1975; from 1975 to 1977 the average rate of increase was 5.4 percent per year; the 1977-1979 increase was not this high (3.9 percent). Larger annual increases in constant dollars, of 4.3 and 4.6 percent, are estimated for 1980 and 1981.[15]

Another indicator of the level of R&D effort of all U.S. industry is the number of full-time-equivalent scientists and engineers employed in that effort. This is shown on figure 4-2.[16] In these terms, 69 percent of all U.S. R&D resources are in industry, the same as industry's share of all R&D funding.[17] The effect of the business cycle is seen in a very slight decline in 1962 and larger declines in 1970, 1971, and 1972. From 1972 to 1980, the rate of increase was 3.0 percent per year, which is close to the estimated 2.7 percent rate of increase in constant-dollar R&D expenditures over the same period. From 1979 to 1980, the increase was 5.6 percent. Over all, this indicator behaves much like the expenditure indicator[18] and gives very nearly the same picture of changes in R&D resources over time. There is considerable consistency between these two indicators of R&D effort, which supports their validity as representations of the level of effort.

Sources of Funding for Industrial R&D

While most of the R&D in the United States is performed by industry, a large part of this effort has been supported by the Federal Government. The Federal share was at its highest in the early 1960's, reaching almost 60 percent. It was still 34 percent of the total in 1979 (see figure 4-1). Thus, the influence of Federal funding on the rate and direction of industrial R&D has been considerable. The Government has goals different from industry's in its support of R&D. The largest fraction of the Federal investment serves the Government's direct needs and responsibilities, such as defense, space, and air traffic control. The Federal Government has also undertaken research and development where there was a national need to accelerate

[11] U.S. Department of Commerce, Bureau of the Census, *Annual Survey of Manufactures, Statistics for Industry Groups and Industries,* Report No. M-78(AS)-1(1981).

[12] *R&D in Industry, 1971,* National Science Foundation (NSF 73-305), p. 61; *R&D in Industry,* 1978, National Science Foundation (NSF 80-307), p. 22; National Science Foundation, preliminary data.

[13] In addition, the Battelle Memorial Institute estimates 1981 industrial R&D expenditures to be $48.05 billion, slightly below the NSF estimate. See *Probable Levels of R&D Expenditures in 1981: Forecast and Analysis* (Columbus, Ohio: Battelle Memorial Institute, 1980), p. 5.

[14] The GNP deflator is used to convert from current dollars to constant, or deflated, dollars. Preliminary results suggest that this deflator may actually underestimate the effect of inflation on industrial R&D costs. See Edwin Mansfield, "Research and Development, Productivity, and Inflation," *Science,* vol. 209 (September 5, 1980), pp. 1091-1093.

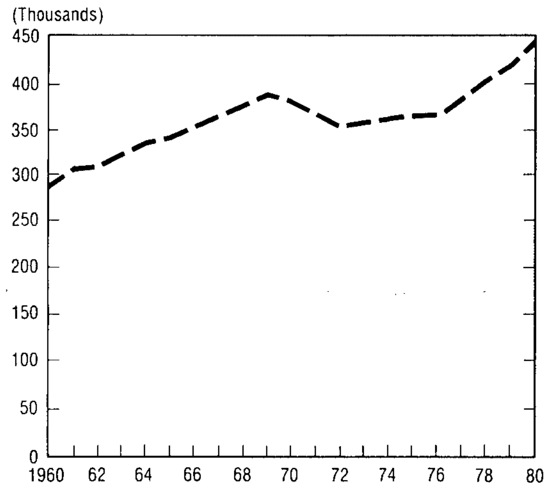
[15] These estimates are based in part on estimates of the implicit price deflators for 1980 and 1981, i.e., of the inflation rate. These estimated deflators are also subject to revision.

[16] The full-time equivalent is the number obtained by distributing each employee's time among R&D and the other work activities.

[17] *National Patterns of Science and Technology Resources,* National Science Foundation (NSF 80-308), p. 33. This estimate is based on yearly average employment, rather than January employment levels.

[18] The correlation coefficient (r) between constant-dollar expenditures and personnel from 1960 to 1978 is .94.

Figure 4-2
R&D scientists and engineers[1] employed in industry



[1] Full-time equivalent, as of January of each year.
NOTE: Preliminary data are shown for 1979-80.
REFERENCE: Appendix table 4-2.
Science Indicators—1980

the rate of development of new technologies in the private sector. This has been especially true when the risk was great or the costs inordinately high, such as with many aspects of energy and transportation. The Federal Government has also supported basic research to meet broad economic and social needs.[19] In some cases, R&D projects were too large or risky to be undertaken by individual firms. In the case of basic research, the performing company frequently cannot expect a payout in a reasonably short time and cannot appropriate all the benefits of the work to itself, so that there may be little incentive to support the research out of company funds.[20] These objectives taken together have helped to determine the limits for Federal participation in industrial research. A number of studies have indicated that the Government is not very effective in developing specific technologies or products to the point where they can fend for themselves in the commercial market. Hence, in spite of considerable interest within the Government in promoting technological innovation, this level of involvement by the Government in the innovation process has been recommended only in special situations.[21] Recent Administration statements support Government funding of long-term research leading to new technologies, especially in energy production. However, the actual bringing of the technologies to the marketplace will be left to private industry.[22]

In contrast to Federal support of R&D, much of private support is intended to increase company productivity.[23] This involves either reducing the cost of existing products through process improvements or yielding more products at the same cost. It is estimated that in 1977 the largest areas of private funding were transportation (24 percent), communications and computers (17 percent), industrial commodities and products (15 percent), and personal home products and services (11 percent).[24] The level of private R&D spending is considered an important contributor to technological innovation, though by itself it is not sufficient to produce innovation. Industry sources often take the view that private R&D will increase only if a more favorable climate for business investment is created. They claim that this could be accomplished through the reduction of inflation, selective tax reductions, and regulatory reform.[25] Federal antitrust policies have also received special attention.[26] Recent proposals are intended to reduce the burden

[19]For an industry view, see *Stimulating Technological Progress*, (New York: Committee for Economic Development, 1980), pp. 61-62.

[20]See Paul Horwitz, "Direct Government Funding of Research and Development: Intended and Unintended Effects on Industrial Innovation," (Cambridge, Mass.: Center for Policy Alternatives, MIT, 1979) and National Science Foundation, Division of Policy Research and Analysis, "Direct Federal R&D Support and Industrial Innovation: A Review of Research Literature," December 1978, pp. 6-8. Individual technical areas are discussed in Simon Ramo, "Science, Technology, and the Economy" in *National Science and Technology Policy Issues, 1979: Part I, A Compendium of Papers*, Printed for the Committee on Science and Technology, U.S. House of Representatives, April 1979, pp. 126-138.

[21]*Stimulating Technological Progress*; Paul Horwitz, "Direct Government Funding of Research and Development: Intended and Unintended Effects on Industrial Innovation," in Christopher T. Hill and James M. Utterback (eds.), *Technological Innovation for a Dynamic Economy* (New York: Pergamon Press, 1979), pp. 278-284; Edwin Mansfield, "The Economics of Innovation," speech presented to the American Chemical Society, September 1979; *A Study of Energy R&D in the Private Sector*, Industrial Research Institute Research Corporation, November 1979, p. 161; *Science and Technology: Annual Report to the Congress*, National Science Foundation, June 1980, pp. 53-60; *Industrial Innovation and Public Policy Options: Report of a Colloquium* (Washington, D.C.: National Academy of Engineering, 1980).

[22]*America's New Beginning: A Program for Economic Recovery*, Part I: *Address by the President to a Joint Session of Congress*, Executive Office of the President, February 1981, p. 3; *Research and Development. Revisions to the Fiscal Years 1981 and 1982 Budgets*, Executive Office of the President, Office of Management and Budget, Energy and Science Division, March 1981, p. 4.

[23]In high-technology industries the emphasis is on new products, while in other industries there is more concern with productivity improvement. In both cases, of course, company profit is the ultimate objective. According to estimates, about 25 percent of company-financed R&D goes into developing internal production processes, while the rest is for new products. See F. M. Scherer, "Research and Development, Patenting, and the Micro-Structure of Productivity Growth," final report to the National Science Foundation, Division of Policy Research and Analysis, June 1981, p. 7.

[24]Bernard N. Samers and Paul R. Lenz, "Estimating Industrial R&D Expenditures by National Functional Objective," report prepared for the National Science Foundation, Division of Science Resources Studies, Aug. 14, 1979, pp. 12-13.

[25]See *Stimulating Technological Progress*, pp. 61-62; Remarks of Lowell Steele in Mogee, "Industrial Innovation and Its Relation to the U.S. Domestic Economy and International Trade Competitiveness," U.S. Library of Congress, Congressional Research Service, October 13, 1978, p. 29; Arthur M. Bueche, Statement Prepared for Hearings before the Committee on Science and Technology, U.S. House of Representatives, April 4, 1979; "Industrial Research Institute Position Statement on Government and Economic Policies to Stimulate Innovation," *Research Management* (January 1980), pp. 13-14.

[26]Douglas H. Ginsburg, *Antitrust, Uncertainty, and Technological Innovation* (Washington, D.C.: National Academy of Engineering, 1980); *Antitrust Guide Concerning Research Joint Ventures*, U.S. Department of Justice, Antitrust Division, November 1980.

of regulation on business and provide tax incentives to promote capital investment.[27] Tax incentives are also intended to stimulate private funding of R&D.[28]

Federal support, in constant dollars, is well below the high level it reached in the mid-1960's, though it has been increasing since its recent low point in 1975. Private support, however, has increased almost every year since 1960 with occasional dips in years of economic slowdown, and is currently at its historically highest level. From 1975 to 1979, company funding increased at an average rate of 5.8 percent per year, twice as fast as the 2.6-percent rate of increase for Federal funding. Increases of 5.5 and 4.6 percent are expected for 1980 and 1981 for private support. Federal support is expected to increase by 1.8 and 4.6 percent for these two years. For R&D-performing companies, the ratio of company R&D funds to net sales was 2.0 percent in 1979. This ratio has been very stable since 1960, ranging from 1.8 to 2.2 percent.[29] Corporate cash flow is another indicator of the amount of company funds available for R&D expenditures. While fewer data are available, cash flow is a better measure of a company's discretionary funds than is R&D divided by net sales. This indicator gives a similar picture. Year-to-year changes in company-funded R&D closely follow the changes in cash flow from the preceding year.[30] This fact raises the suggestion that corporate R&D expenditures are an effect of company prosperity,[31] though in other contexts they are also considered a cause of such prosperity. Recent results suggest that the returns to private R&D funding, in terms of company profits, were depressed in the first half of the 1970's and recovered in the second half. Company funding of R&D may have fluctuated in part because of these fluctuations in profits.[32]

Resources for Basic Research, Applied Research, and Development in Industry

For purposes of analysis, R&D expenditures can be divided into basic research, applied research, and development, although the model of the R&D process that assumes that every project goes through these stages in rigid order, and that information passes in only one direction along this chain, has long since been discredited.[33] This threefold division is useful because it allows industrial R&D efforts, considered at an aggregate level, to be placed on a scale from the long-term, speculative, and general to the short-term, predictable, and specific. Efforts closer to the development end of the spectrum tend to be more expensive, so that fewer projects of this kind are funded. Shifts in industry's emphasis in funding basic research, applied research, or development reflect changes in its ability and willingness to invest in the long-range future.

Expenditures for industrial R&D classified in this way are shown in figure 4-3. While development expenditures have increased steadily year by

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[27] *America's New Beginning: A Program for Economic Recovery*, Part III: *A White House Report*, Executive Office of the President, February 1981, pp. 14-21.

[28] *America's New Beginning: A Program for Economic Recovery*, Part I: *Address by the President to a Joint Session of Congress*, Executive Office of the President, February 1981, p. 7. This subject is discussed at length in the chapter on Resources for Research and Development.

[29] *R&D in Industry, 1971*, National Science Foundation (NSF 73-305), p. 63; *R&D in Industry, 1978*, National Science Foundation (NSF 80-307), p. 23.

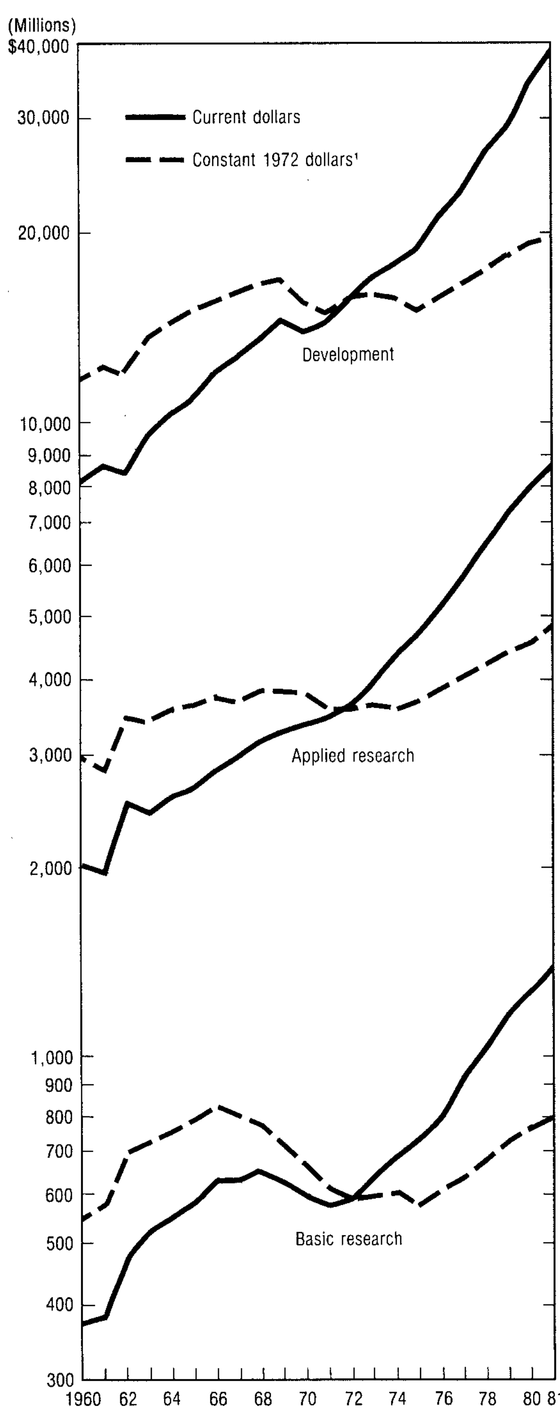
[30] The correlation coefficient (r) between total company R&D funding and total corporate cash flow from 1958 to 1978 is .88. A better test can be made by deflating both series and correcting for autocorrelation, in order to remove specious correlation. Doing this (by Cochrane-Orcutt iteration) leads to a correlation coefficient of 1.00 between R&D expenditure and the previous year's cash flow. The correlation is much poorer with the cash flow for the same year or the following year. For cash flow data, see *Economic Report of the President*, January 1980, p. 295. It must be noted that these cash flow data represent more companies than those reporting R&D expenditures. Also see M. Ishaq Nadiri, "Contributions and Determinants of Research and Development Expenditures in the U.S. Manufacturing Industries," National Bureau of Economic Research Working Paper No. 360, June 1979.

[31] See Lawrence Goldberg, *The Influence of Federal R and D Funding on the Demand for and Returns to Industrial R and D* (Alexandria, Va.: Public Research Institute, 1979), p. 1, and the remarks of Lowell Steele in Mogee, *Industrial Innovation and Its Relation to the U.S. Domestic Economy and International Trade Competitiveness*, U.S. Library of Congress, Congressional Research Service, October 13, 1978, p. 29.

[32] Scherer, p. 22.

[33] See, for example, Patrick Kelly and Melvin Kranzberg, *Technological Innovation, A Critical Review of Current Knowledge*, vol. 1, "The Ecology of Innovation," National Technical Information Service Report No. PB 242550, February 1975, p. 17; Thane Gustafson, "Survey of the Structure and Policies of the U.S. Federal Government for the Support of Fundamental Scientific Research," in *Systems for Stimulating the Development of Fundamental Research*, (Washington, D.C.: National Research Council, Commission on International Relations, 1978), pp. 1-70 through 1-82. For another division of the R&D continuum see Frank Lynn, "An Investigation of the Rate of Development and Diffusion of Technology in Our Modern Industrial Society," (Washington, D.C.: National Commission on Technology, Automation and Economic Progress, February 1966) vol. II, pp. II 31-91.

Figure 4-3
Industrial expenditures for basic research, applied research, and development



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Preliminary data are shown for 1978-80 and estimates for 1981.
REFERENCE: Appendix table 4-3. Science Indicators—1980

year in current-dollar terms, the picture is different when correction is made for inflation. In deflated dollars, 1969 was a high point, after which weaknesses in the economy led to oscillations and a general decline in development spending. Since the recent low point in 1975, constant-dollar development expenditures have risen by 4.6 percent per year, and exceeded the 1969 level only in 1977. For 1980 and 1981, 4.1- and 4.7-percent increases are estimated. The pattern for applied research has been very similar to that for development.

In the case of basic research the level of expenditure dropped from 1968 to 1971, even in current dollars. In constant-dollar terms, the drop began in 1967 and extended through 1972. Another decrease occurred in 1975. However, the upturn that began in 1976 is expected to continue at least through 1981. From 1975 to 1979 the rate of increase was 5.9 percent per year, higher than the applied research and development increases. Some industry spokesmen attribute this upturn to a desire on the part of industry to reverse the disadvantageous movement of earlier years toward shorter-term R&D projects.[34] Smaller percentage increases are projected for 1980 and 1981.

Development accounted for 78 percent of total expenditures in 1979, while applied research had 19 percent and basic research had 3 percent. Development's share has fluctuated slightly, between 74 percent in 1962 and 79 percent in 1972 and 1973. Basic research has seen proportionately wider shifts: From 4.3 percent of the total in 1962 it gradually and steadily declined to the level of 3.0 percent in 1972, where it has virtually remained since. By contrast, total national R&D expenditures were allocated as follows: 64 percent to development, 22 percent to applied research, and 13 percent to basic research.[35]

Federal support of industrial R&D is much more concentrated on the development end of the spectrum than is industry's own support. About 2 percent of Government funding goes to basic research, while 13 percent goes to applied research and 85 percent to development.[36] By contrast, industry puts 4 percent of its R&D funds into basic research, 22 percent into applied research, and only 74 percent into development. Thus the level of basic research in industry is maintained primarily by industry itself. Since 1971, industry's own contribution to industrial basic research has been more than three times the Federal contribution.

[34]"More Speed Behind R&D Spending," *Business Week*, (July 7, 1980), pp. 47-70.

[35]See appendix table 2-9.

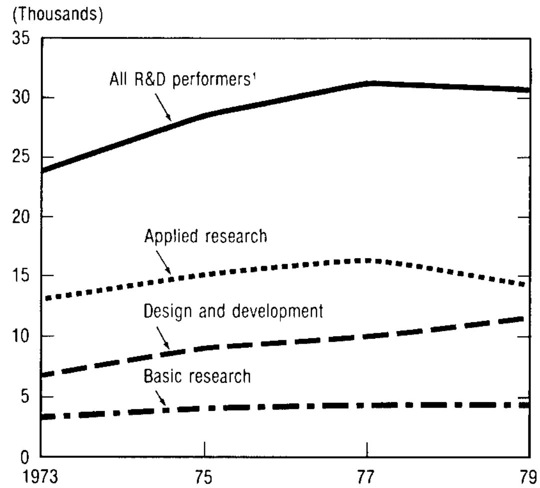
[36]*National Patterns of Science and Technology Resources, 1980*, pp. 25-28.

The distribution of industrial R&D effort among basic research, applied research, and development can also be seen in terms of the numbers of science and engineering personnel that work in each area. Forty percent of all scientists and engineers in industry are connected in some way with the R&D effort (including design and management). (See table 4-1.)[37] In terms of personnel employed, basic research amounts to 5 percent of all R&D performance. This is more than the share basic research receives of all R&D *funding* because applied research and development have higher capital, material, and utility costs. Applied research employs about 18 percent of R&D-performing personnel, which is about the same as its share of funding. Design and development together account for the remaining 76 percent. In addition to the personnel who perform R&D, a second group, one-third as large as the first, is involved in supervising, administering, and managing R&D.

Scientists and engineers with doctoral degrees make up an important subgroup. In a sense, degree level is an indicator of the quality of scientific and engineering personnel. Figure 4-4 shows the trends in industry's use of these highly trained personnel in R&D-related areas. While the total number of doctoral scientists and engineers increased in every 2-year period, the number primarily working in the performance of R&D decreased from 1977 to 1979 because of a drop in the number primarily engaged in applied research. This drop

Figure 4-4.

Doctoral scientists and engineers employed in industrial R&D, by primary work activity



[1]Includes design.

REFERENCE: Appendix table 4-4.

Science Indicators—1980

[37]This table shows a considerably higher number of R&D scientists and engineers in industry than does appendix table 4-2. The difference is due to differences in definition. While the present table includes all who report R&D as their primary work activity, appendix table 4-2 covers only the working time that scientific and engineering employees put into R&D.

Table 4-1. Scientists and engineers employed in industrial R&D[1], by primary work activity: 1978

Activity	Number in thousands	Percent of all industrial S/E's
All scientists and engineers	1,528.1	—
Total R&D	613.3	40
R&D performance[1]	460.5	30
Basic research	24.9	2
Applied research	84.8	6
Design and development	350.8	23
R&D management	152.8	10

[1]Includes design.

SOURCE: National Science Foundation, *U. S. Scientists and Engineers 1978* (NSF 80-304), p. 51.

Science Indicators—1980.

does not show up in the funding data.[38] By the same token, the small decreases that occurred in constant-dollar funding for basic research, applied research, and development from 1973 to 1975 were not accompanied by a drop in doctoral personnel.

The fraction of all doctoral industrial scientists and engineers primarily engaged in the performance of R&D has decreased since 1975 because of an overall decline in applied research and only a small increase in basic research (see appendix table 4-4). In 1979, 37 percent of all doctoral scientists and engineers in industry were primarily engaged in the performance of R&D (which is above the 30 percent of *all* industrial scientists and engineers employed in the performance of R&D in 1978). Thus, doctoral scientists and engineers employed in industry are slightly more concentrated in R&D than are all scientists and engineers taken together. The research orientation of these employees is further seen in the 15 percent of doctoral scientists and engineers engaged in R&D performance who work in basic research, well above the 5-percent figure for *all* industrial scientists and engineers performing R&D. While some of these scientists and engineers spend their entire industrial careers utilizing their research skills, others move on to other functions within industry. As a result, older employees are more likely to move out of research than into it.[39]

Resources for R&D in Individual Industries

While data pertaining to the industry sector as a whole are important for obtaining a broad picture of this component of the U.S. economy, it is also important to look at individual industries. R&D is much more important to some industries than to others, and some contribute far more than others to the total of industrial R&D.

Figure 4-5 shows the levels of R&D funding, from 1960 to 1979, for the eight industries in which the greatest amounts of R&D funding occur.[40] The data show the concentration of industrial R&D performance in a few industries. (See appendix table 4-5.) The first one, aircraft and missiles, accounts for 22 percent of all industrial R&D. The first five industries account for 79 percent.[41]

Almost all industries have shown steady long-term increases in current-dollar R&D funding over the period shown on the figure. The aircraft and missiles industry is the main exception, because of a drop in both Federal and company funding at the end of the Apollo program.[42] The slowdown of the space program also affected Federal funding in professional and scientific instruments and electrical equipment. In constant-dollar terms, many industries show a sag in R&D funding in the early 1970's, but a turnaround began in the mid-1970's. Especially large increases from 1975 to 1979 occurred in scientific and mechanical measuring instruments (72 percent), motor vehicles and equipment (42 percent), electronic components (41 percent), paper and allied products (41 percent), and nonmanufacturing (38 percent). Declines occurred in rubber products (9 percent), and radio and TV receiving equipment (7½ percent), with only small increases in textiles and apparel (2 percent) and ferrous metals and products (5 percent). Almost all industries show an increase from 1978 to 1979. The exceptions are stone, clay, and glass products and "other manufacturing."

The primary metals industry is beginning to recover from the decline in constant-dollar R&D funding in 1977 and 1978. Metals producers traditionally have not been committed to intensive R&D programs, partly because it can take as much as 20 years to bring a new technology from the laboratory to the workplace and the industry has been much too cyclical to sustain such an effort.[43]

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[38] The drop was accompanied by large increases in consulting, sales and professional services, and "other" activities. The 1977 applied researchers may have taken up these new activities, or they may have left industry altogether by 1979. Another possibility is that the data reflect a change in the classification of R&D managers beginning in 1979. See *Characteristics of Doctoral Scientists and Engineers in the United States: 1979*, National Science Foundation (NSF 80-323), p. 11.

[39] Lindsey R. Harmon and Betty D. Maxfield, *Career Patterns of Doctoral Scientists and Engineers, 1973-1977* (Washington, D.C.: National Academy of Sciences, National Research Council, 1979), p. 18.

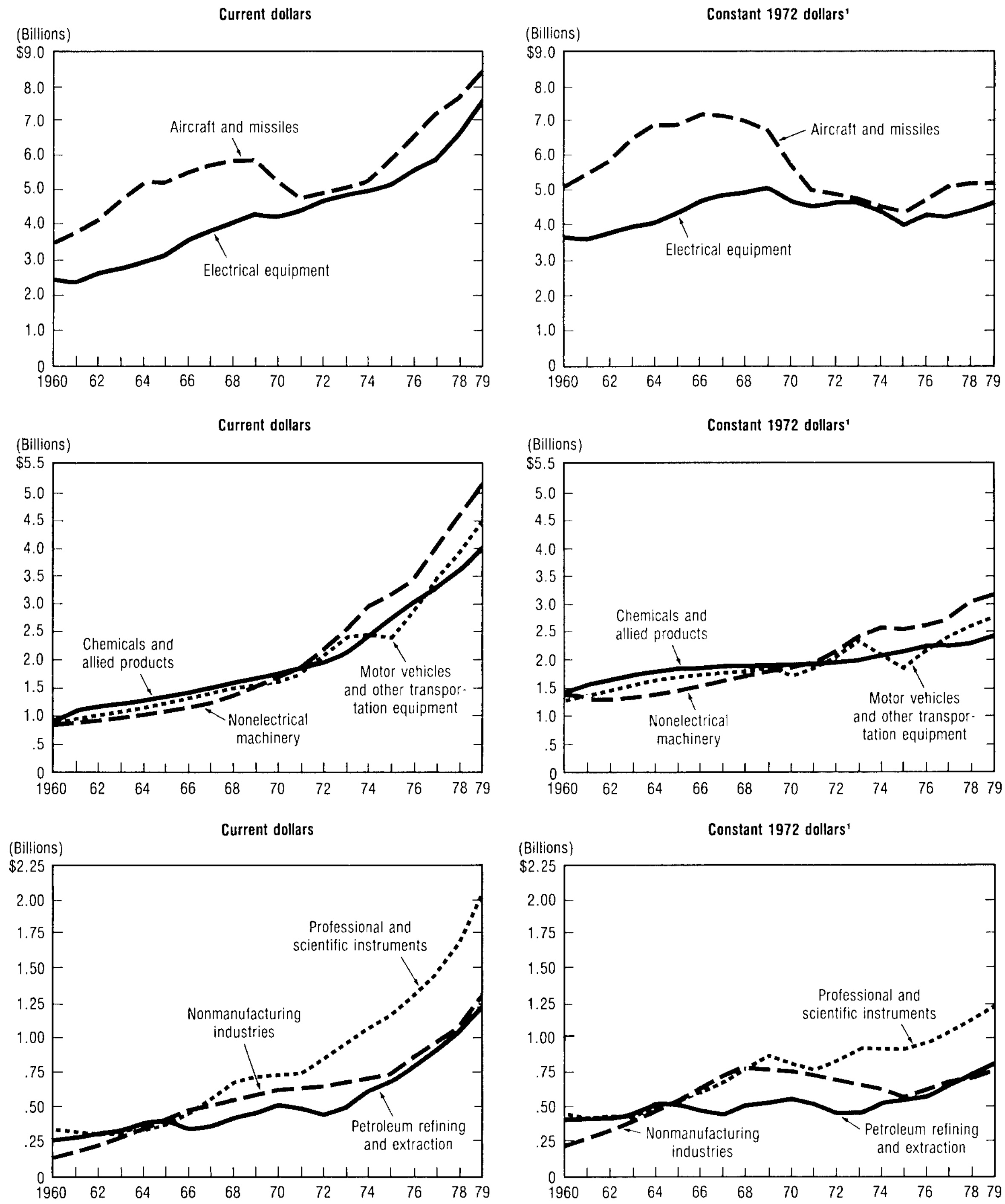
[40] For the remaining industries, see appendix table 4-5. Industries are classified in terms of the Standard Industrial Classification for establishments. Each corporation responding to the survey is assigned to a single SIC classification. Other sources of R&D data by individual industry are the Federal Trade Commission's Annual Line of Business Reports and the 10K forms that corporations file with the Securities and Exchange Commission, as reported annually in the first July issue of *Business Week*. The latter reports R&D expenditures by selected individual companies but does not aggregate them in terms of the SIC.

[41] R&D efforts are also concentrated in terms of individual companies. For example, in 1979 four companies accounted for 20 percent of all industrial R&D expenditures, according to preliminary data from National Science Foundation.

[42] *R&D in Industry, 1978*, pp. 14, 17.

[43] "R&D Spending at 683 Companies: Another Record Year," *Business Week* (July 2, 1979), pp. 52-72.

Figure 4-5
R&D expenditures by selected industries



[1]GNP implicit price deflator used to convert current dollars to constant 1972 dollars.
NOTE: Preliminary data are shown for 1978 and 1979.
REFERENCE: Appendix table 4-5.

Science Indicators—1980

The greatest increases in R&D spending from 1978 to 1979 occurred in "other chemicals" (17 percent, in constant dollars), scientific and mechanical measuring instruments (15 percent), electronic components (13 percent), and nonmanufacturing industries (11 percent).

The increase in aerospace R&D in recent years is attributed in part to intensified foreign competition, in particular an effort to compete with the European-built Airbus.[44] The semiconductor industry is credited with an increase, again largely due to intense technological competition. Oil service and supply R&D is supposed to have increased because of new efforts to improve drill bits and other drilling apparatus and to detect the presence of oil or gas while a well is being drilled. Instrument makers have increased their R&D, possibly because new toxicity testing requirements in the chemical and drug industries have created a need for better analytic equipment. The fuel industry has raised its R&D effort because of aggressive programs underway at all large companies to convert coal into gases, or, preferably, liquids.

From 1979 to 1980, large current-dollar increases in R&D are estimated for many industries.[45] Several industries are expected to be 25 percent or more above their 1979 expenditures: rubber products; stone, clay, and glass; aerospace; and iron and steel. Increases close to 25 percent are expected for nonelectrical machinery and transportation equipment. Estimates are also made for 1981.[46] Large increases above the 1979 level (40 percent, or more, in current dollars), are expected in petroleum; electrical machinery; and stone, clay, and glass. Increases almost as large are expected in the food and paper industries.

Federal Component. While the Federal Government provided nearly a third of all industrial R&D support in 1979, this support was very unevenly distributed among the various industries. Some industries are relied on much more than others in achieving Government objectives. As table 4-2 shows, the aircraft and missiles industry and the electrical equipment industry receive the greatest shares of their R&D support from the Government. However, these shares are the lowest they have been since the early 1960's, when Federal support reached 91 percent of the total in the case of aircraft and missiles R&D, and 65 percent in the case of electrical equipment. Both industries are active in providing spacecraft, weaponry, and military aircraft to the Federal Government. Since significant increases are planned in the R&D programs of the Department of Defense, these industries can expect increased Government R&D funding in the near future.[47] The electrical equipment industry also administers four federally funded research and development centers primarily devoted to energy R&D.[48] Nonmanufacturing industries have a very high percentage of their R&D supported by the Government. This is particularly true of business services such as R&D laboratories, management and consulting services, and data processing, where the Government provides 80 percent of all R&D funds.[49]

Private Component. Table 4-2 shows that over the 10 years from 1969 to 1979 company funding for R&D grew substantially in many industries. This is especially true in nonelectrical machinery, which includes computers. In percentage terms, increases were also high in instruments, with a very high increase going into scientific and mechanical measuring instruments, and in nonmanufacturing industries. All these industries nearly doubled their constant-dollar R&D funding. Computers and instruments have had especially good sales in recent years. In the nonmanufacturing industries, increases were largely due to new R&D activity in service industries such as electrical, gas, and sanitary services. Aircraft and missiles is the only industry showing a decrease. From 1978 to 1979, company funding for R&D increased by 6 percent in constant dollars for all industry.[50] Increases larger than this occurred in scientific and mechanical measuring instruments, aircraft and missiles, nonmanufacturing industries (especially in electric, gas, and sanitary services), and electrical equipment. On the

[44]"More Speed Behind R&D Spending," *Business Week* (July 7, 1980), pp. 47-70. The European manufacturers' effort to develop the Airbus and market it in the United States was stimulated in turn by their perception that the U.S. airline industry was ready to purchase a new generation of aircraft and that U.S. industry was already preparing to develop such aircraft.

[45]*Probable Levels of R&D Expenditures in 1980: Forecast and Analysis* (Columbus, Ohio: Battelle Memorial Institute, 1979), p. 12.

[46]*Probable Levels of R&D Expenditures in 1981: Forecast and Analysis* (Columbus, Ohio: Battelle Memorial Institute, 1980), p. 12.

[47]*Research and Development. Revisions to the Fiscal Years 1981 and 1982 Budgets*, Executive Office of the President, Office of Management and Budget, Energy and Science Division, March 1981, pp. 1, 3.

[48]"Greatest Increase in 1978 Industrial R&D Expenditures Provided by 14% Rise in Companies' Own Funds," *Science Resources Studies Highlights*, National Science Foundation (NSF 80-300).

[49]National Science Foundation, preliminary data for 1979.

[50]National Science Foundation, preliminary data.

Table 4-2. Company[1] and Federal funding of industrial R&D in constant dollars[2] for selected industries

[Dollars in millions]

Industry	1969 Company[1] funding	1969 Federal funding	1969 Federal as percent of total	1979 Company[1] funding	1979 Federal funding	1979 Federal as percent of total
Total	$11,357	$9,737	46	$15,521	$7,582	33
Chemicals and allied products	1,691	221	12	2,231	233	9
Industrial chemicals	970	190	16	1,019	221	18
Drugs and medicines and other chemicals	721	31	4	1,212	12	1
Petroleum refining and extraction	527	12	2	665	87	12
Primary metals	285	12	4	356	20	5
Ferrous metals and products	156	2	1	177	3	2
Nonferrous metals and products	129	10	7	179	17	9
Fabricated metal products	200	9	4	251	22	8
Nonelectrical machinery	1,482	300	17	2,746	413	13
Electrical equipment	2,255	2,754	55	2,680	1,981	43
Aircraft and missiles	1,560	5,213	77	1,401	3,767	73
Professional and scientific instruments	582	273	32	1,106	137	11
Scientific and mechanical measuring instruments	105	37	26	342	22	6
Optical, surgical, photographic, and other instruments	477	236	33	764	116	13
Nonmanufacturing industries	239	516	68	413	396	49

[1]Includes all sources other than the Federal Government.
[2]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: Preliminary data are shown for 1979.

REFERENCE: Appendix table 4-6.

Science Indicators—1980.

other hand, there were very small increases in private funding of lumber and wood products R&D, as well as R&D in office machines and ferrous metals.

Industry's investment in R&D from its own funds also includes the funds that American multinational corporations spend for the performance of R&D by their foreign affiliates. This investment is controversial because, in the view of some, U.S. corporations evade domestic environmental protection and product safety regulations by conducting some research and developing some products abroad.[51] It is also argued that sharing of technology with foreign affiliates, and especially cooperating with them in R&D, will speed up the diffusion of U.S. technology abroad.[52] Both affiliates and competitors supposedly will acquire technical abilities that the United States developed at great cost, so that both the commercial and the strategic military positions of the United States will gradually be eroded and jobs that could be filled by Americans will go overseas. Supporters of overseas investment argue that foreign investment and the possibility of foreign sales augment the incentive to perform domestic R&D and therefore increase its amount, with consequent technological benefit to the United States.[53]

Table 4-3 shows this investment for recent years. Total R&D expenditures in foreign affiliates of U.S. companies increased by 16 percent per year[54] from 1974 to 1979, while the domestic rate of increase was only 11 percent. On the average, foreign

[51]However, those products that are shipped to the United States are then subject to U.S. regulations.

[52]For further discussion, see the chapter on International Science and Technology.

[53]Robert Gilpin, "Technology and the National Economy," in *National Science and Technology Policy Issues: 1979, Part I: A Compendium of Papers*, Committee on Science and Technology, U.S. House of Representatives, April 1979; Edwin Mansfield, Anthony Romeo, and Samuel Wagner, "Foreign Trade and U.S. Research and Development," *The Review of Economics and Statistics* (1979), pp. 49-57.

[54]These data include R&D funds provided by the foreign affiliate, i.e., any affiliate outside the 50 States or the District of Columbia. However, they do not include funds provided by foreign governments or other outside organizations.

Table 4-3. Company[1] funds for domestic and foreign-affiliate R & D for selected industries

[Dollars in millions]

Industry	1974 Domestic R&D	1974 Foreign R&D	1974 Foreign as percent of domestic	1979 Domestic R&D	1979 Foreign R&D	1979 Foreign as percent of domestic
Total	$14,667	$1,290	8.8	$25,264	$2,709	10.7
Chemicals and allied products	2,236	208	9.3	3,631	450	12.4
Petroleum refining and extraction	603	(2)	(2)	1,082	91	8.4
Primary metals	350	3	0.9	580	14	2.4
Fabricated metal products	299	(2)	(2)	409	35	8.6
Nonelectrical machinery	2,473	258	10.4	4,469	542	12.1
Electrical equipment	2,704	228	8.4	4,363	475	10.9
Motor vehicles and other transportation equipment	2,141	364	17.0	3,692	(2)	(2)
Aircraft and missiles	1,278	42	3.3	2,281	127	5.6
Professional and scientific instruments	908	39	4.3	1,801	87	4.8
Nonmanufacturing industries	305	3	1.0	672	4	.6

[1]Includes all sources other than the Federal Government.
[2]Not separately available.

NOTE: Preliminary data are shown for 1979.

REFERENCE: Appendix table 4-7.

Science Indicators—1980.

expenditures are equal to about 11 percent of company-funded domestic spending. However, the ratio is much higher for some industries. The motor vehicles industry has had particularly high foreign R&D investments as a percentage of domestic R&D. Chemicals (which includes drugs) and nonelectrical machinery (which includes computers) are also high. From 1978 to 1979, increases in R&D dollars spent abroad were very large, in percentage terms, in aircraft and missiles. They were also high in electronic components, fabricated metal products, and instruments, though the total foreign R&D expenditure in these industries remains relatively low. The increase for all industries was 23 percent.

From industry's point of view, the main reason for these foreign expenditures is "meeting local market conditions," rather than more favorable personnel and materials costs.[55] Growing sales outside the United States usually stimulate increased foreign R&D. Some large multinational companies try to achieve an optimum balance of technological development and marketing in the various countries in which they operate. After a company establishes a business base in a foreign country, the next step often is to begin technology development efforts in that country. Some host countries insist on this, as a way of developing their own technological infrastructure. Some products developed in foreign laboratories can only be sold overseas.

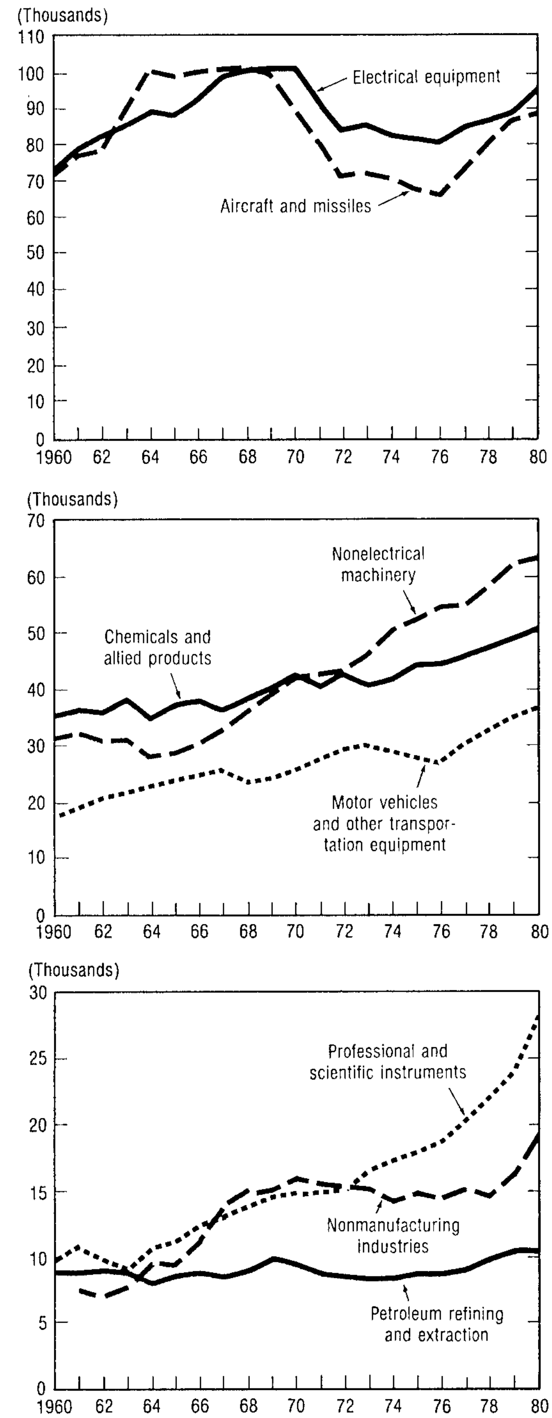
Local customers' needs are especially important to the computer industry.[56] In chemicals, such products as fertilizers and household chemicals have to be specially tailored to local conditions. Such efforts involve development more than basic or applied research. Drug companies increased their foreign R&D expenditures, especially from 1974 to 1975, because of a liberalization of FDA rules in 1975 regarding the acceptance of test results from foreign markets. In general, only about 15 percent of the major U.S. industrial R&D performers spend any portion of their company R&D funds outside the United States, but these few firms account for nearly half of domestic company-funded R&D in the United States.

Personnel Resources. The resources that various industries devote to R&D can be seen in the personnel effort that they allocate to that activity, as well as in the funds expended. Figure 4-6 shows the full-time-equivalent R&D personnel in those

[55]"U.S. Industrial R&D Spending Abroad," *Reviews of Data on Science Resources*, National Science Foundation (NSF 79-304).

[56]Ibid.

Figure 4-6
R&D scientists and engineers[1] employed in selected industries



[1]Full-time equivalent, as of January of each year.
NOTE: Preliminary data are shown for 1979-80.
REFERENCE: Appendix table 4-8.

Science Indicators—1980

industries with the greatest levels,[57] and is thus comparable to figure 4-5. In these terms, the electrical equipment industry has a higher level of R&D effort than the aircraft industry, but these are still the two leading industries. The next three industries in terms of personnel are also the highest on figure 4-5, although their order once again is different.

Most industries show an increase in R&D personnel from 1979 to 1980. Some of these, like electrical equipment, aircraft, and nonmanufacturing, are recovering from previous dips in R&D employment. Others, like nonelectrical machinery and instruments, are continuing long-term advances. From January 1979 to January 1980, the largest increases, in percentage terms, occurred in scientific and mechanical measuring instruments, nonmanufacturing, "other chemicals," and rubber. These were some of the industries showing the largest funding increases from 1978 to 1979.[58] Similarly, the industries with decreases in personnel ("other manufacturing"; stone, clay, and glass; ferrous products; textiles and apparel; and food) were for the most part the ones that did not show large constant-dollar funding increases from 1978 to 1979. On the other hand, the petroleum industry had a large increase in R&D funding from 1978 to 1979 without increasing its R&D scientific and engineering personnel from January 1979 to January 1980.

Summary—R&D Efforts Section

The industrial sector performs about 70 percent of the R&D done in the United States, as measured by either dollars or personnel. R&D is a significant expense for industry, of the same order of magnitude as new plant and equipment. In current-dollar terms, R&D funding has increased every year since the 1950's, with recent estimated increases of 14 to 15 percent per year. When allowance is made for inflation, however, funding reached a recent low point in 1975; annual increases since that time have fluctuated, but currently seem to be about 4½ percent per year. The number of scientists and engineers engaged in industrial R&D has been increasing steadily since 1972, but currently is increasing at a higher rate: about 5½ percent per year.

Private funding accounts for two-thirds of industrial R&D. In high-technology industries, this funding is directed mostly toward new product development. Much of it also goes to reducing

[57]Data for all industries can be seen in appendix table 4-8.
[58]See appendix table 4-5.

production costs, particularly in the less technology-intensive industries. Unlike Federal support, private support in constant dollars has increased almost every year from 1960 to 1979, with only occasional dips in years of economic slowdown, and since 1975 has been increasing faster than Federal support. The ratio of private R&D to net sales has been almost constant at 2 percent since 1960. Private R&D also closely follows corporate cash flow, which suggests that improvements in company prosperity may themselves lead to increased company-supported R&D.

The remaining third of industrial R&D support has been provided by the Government to meet public needs and, to a much lesser extent, to develop private-sector technical capability in cases where market incentives for private-sector investment are not adequate. In constant dollars, Federal support in 1979 was well below the level of the mid-1960's, though it has been increasing since 1975.

Private investment for R&D in foreign affiliates is supported mainly by a small number of multinational corporations with large foreign sales. This investment allows the companies to tailor their products to specific foreign markets and, especially in the case of the drug industry, to conduct research and develop products that would be highly restricted in the United States. From 1974 to 1979, foreign R&D expenditures increased faster than domestic expenditures, reaching a level of 11 percent of domestic privately funded R&D. The industries most involved were motor vehicles, nonelectrical machinery (including computers), electrical equipment, and chemicals (including drugs).

While most industries have shown steady increases in constant-dollar R&D funding since 1975, this pattern is not universal. The ferrous metals, rubber, textiles, and radio and TV equipment industries show declines in total R&D support from 1975 to 1979. The greatest increases, on the other hand, are in scientific and mechanical measuring instruments, nonmanufacturing industries, electronic components, and paper. The industries with the greatest or smallest increases in R&D expenditures from 1978 to 1979 usually also had the greatest or smallest increases in the employment of R&D scientists and engineers. For 1980 and 1981, increases are again projected for most industries. Increases have occurred in the aerospace industry because of efforts to produce a new generation of civilian aircraft and compete with the European-built Airbus. R&D in oil service and supply and fuels has grown because of energy needs. Instrument makers are believed to profit from pollution abatement requirements in other industries.

While basic research, applied research, and development are not sequential stages in a simple linear process, R&D resources classified in these terms are likely to indicate the levels of industrial investment in shorter-term and longer-term projects, and to indicate any shifts in emphasis. In 1979, 78 percent of all R&D was development, 19 percent was applied research, and 3 percent was basic research. In constant-dollar terms, all three have been increasing since 1975 and are expected to continue to do so through 1981. However, the rapid upturn in basic research in the last few years may reflect a desire to reverse the movement of earlier years toward shorter-term R&D projects. Government support of industrial R&D is more oriented to the development end of the spectrum than is support from industry. In terms of personnel, basic research employs 5 percent of all industrial scientists and engineers who work in R&D and 15 percent of those holding doctoral degrees. Trends in doctoral employment only roughly follow trends in funding.

UNIVERSITY-INDUSTRY COOPERATION IN R&D

While the industrial R&D effort is very large and is vital to the development of technology and the improvement of productivity, it does not go on in isolation. Industry draws on the research performed in universities, especially on the basic research that industry is sometimes reluctant or unable to perform itself.[59] The various fields of science develop mainly at universities. Through its contacts with universities, industry keeps up with those developments that can be adapted to commercial application. At the same time, industrial

[59] For general discussions, see Denis J. Prager and Gilbert S. Omenn, "Research, Innovation, and University-Industry Linkages," *Science*, vol. 207 (January 25, 1980), pp. 379-384; Peter F. Drucker, "Science and Industry, Challenges of Antagonistic Interdependence," *Science*, vol. 204 (May 25, 1979), pp. 806-810; Neal H. Brodsky, Harold G. Kaufman, and John D. Tooker, *University/Industry Cooperation: A Preliminary Analysis of Existing Mechanisms and Their Relationship to the Innovation Process* (New York: New York University, Center for Science and Technology Policy, June 1980); Martin J. Cooper, "Universities and the Private Sector—Opportunities for Mutual Gain in the Decade Ahead," *Journal of the Society of Research Administrators*, vol. 10 (winter 1979), p. 27; *Industry and the Universities: Developing Cooperative Research Relationships in the National Interest* (Washington, D.C.: National Commission on Research, August 1980); *Summary of House and Senate Hearings on Government-University-Industry Relations*, Subcommittee on Science, Research, and Technology, Committee on Science and Technology, U.S. House of Representatives, June 1980.

needs are a source of problems for university research and stimulate some of that effort.[60] The level and effectiveness of university-industry cooperation are important current policy issues.

Contacts and transfers of information between universities and industry take place in many different ways. The results of university research are made available to industry through professional publications and through presentations at professional meetings. University faculty often serve as part-time consultants to industrial companies, sometimes on a long-term basis,[61] or even become affiliated with such companies.[62] One of the most important contributions colleges and universities make to industry is in the production of new graduates, who bring to industry the latest in knowledge and technique.[63] In recognition of this, industry has supported scholarships and fellowships at universities in addition to providing direct grants for specific R&D projects and unrestricted institutional grants.

The link between industry and universities has been given particular attention recently because of its importance to the progress of industrial innovation. Since university research benefits the entire economy, some industry representatives are interested in seeing it expand.[64] In some outstanding cases, cooperative arrangements have been established between particular companies and particular universities.[65] Ways are being sought to encourage the development of university-industry interaction, including the formation of additional "generic technology centers" at universities.

Industry Support of University R&D

Corporate support of university activities is an important area of university-industry interaction. Such support ranges from voluntary (tax deductible) gifts by corporations to expenses for direct procurement of services. Examples of the former are undirected gifts to the university fund, capital contributions to specific departments or laboratories, and industrial fellowships. Procurements include prototype development and testing, contract research, consulting, and training of industry employees.[66]

R&D is thus only one component of industry's support of universities. According to one estimate, 18 percent of such support in 1978 was for departmental and research grants.[67] Figure 4-7 shows industry's support for university R&D for the period 1960-1981. This figure shows only R&D directly funded through grants and contracts and thus excludes many other mechanisms for R&D support. For example, it does not include unrestricted grant funds from industry that the institution chooses to spend on research. It also does not include R&D funds from nonprofit foundations ultimately supported by industry.

Figure 4-7 shows a steady increase in industry support of university R&D, in terms of current dollars. In constant dollars, support reached a low point in the mid-1960's and has more than doubled since then. Industry provided 7.5 percent of all university R&D support in 1953.[68] This fraction declined to 2.4 percent in 1966, mainly because of the great increase in Federal support. Industry's

[60] See H. W. Paxton, "University-Industry Cooperation, with Special Reference to the Steel Industry," Statement before the Subcommittee on Science, Research, and Technology, Committee on Science and Technology, U.S. House of Representatives, August 2, 1979; Mary Ellen Mogee, *The Relationship of Federal Support of Basic Research in Universities to Industrial Innovation and Productivity*, U.S. Library of Congress, Congressional Research Service, March 12, 1979, pp. 23-38.

[61] Rustum Roy, "University-Industry Interaction Patterns," *Science*, vol. 178 (December 1, 1972), pp. 955-960; J. E. Goldman, "Science, Technology, and Innovation," in *National Science and Technology Policy Issues: 1979. Part I: A Compendium of Papers*, Committee on Science and Technology, U.S. House of Representatives, April 1979.

[62] J. E. Goldman, "How to Encourage Innovation," in *National Science and Technology Policy Issues: 1979. Part I: A Compendium of Papers*, Committee on Science and Technology, U.S. House of Representatives, April 1979.

[63] Mary Ellen Mogee, *The Relationship of Federal Support of Basic Research in Universities to Industrial Innovation and Productivity*, p. 10.

[64] *Stimulating Technological Progress*, pp. 63-64.

[65] "Industry R&D Renews the Old Campus Ties," *Chemical Week*, vol. 124 (Feb. 21, 1979), pp. 38-39; David M. Kiefer, "Forging New and Stronger Links Between University and Industrial Scientists," *Chemical and Engineering News*, vol. 58 (December 8, 1980), pp. 38-51.

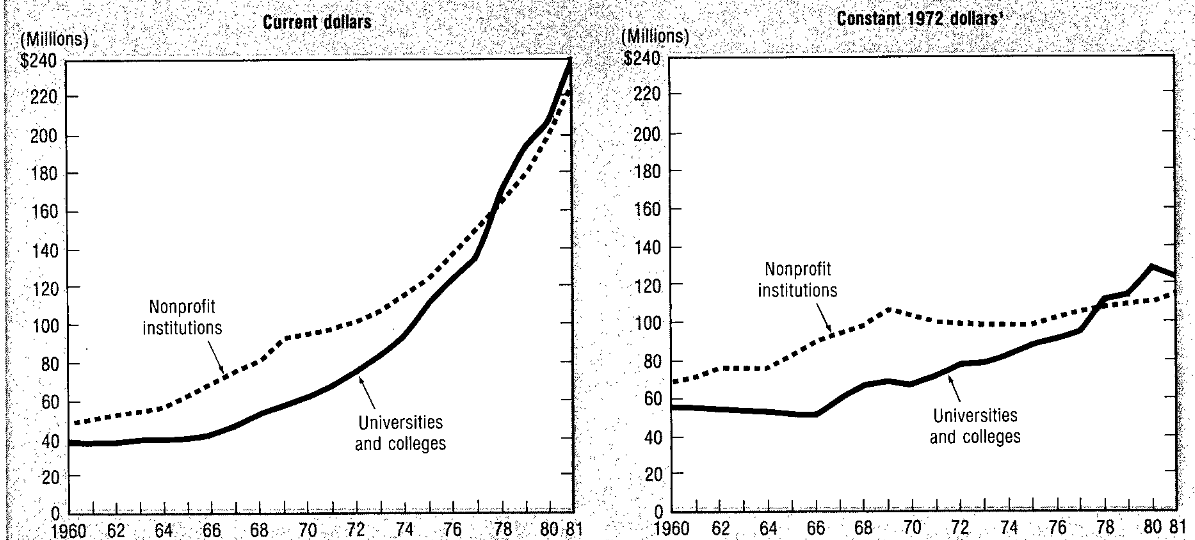
On NSF programs in this area, see Jack T. Sanderson, "University-Industry Coupling: The National Science Foundation Model," in *Technology and Innovation For Manufacturing*, Proceedings of a Conference, May 4, 5, 1979, Committee on Science and Technology, U.S. House of Representatives, and Richard C. Atkinson, statement before the Subcommittee on Science and Technology, U.S. House of Representatives, July 31, 1979.

[66] Denis J. Prager and Gilbert S. Omenn; Neal H. Brodsky, Harold G. Kaufman, John D. Tooker, pp. 13-17.

[67] Ibid., p. 14.

[68] *National Patterns of Science and Technology Resources, 1980*, p. 25; National Science Foundation, preliminary data.

Figure 4-7
Industry's expenditures for R&D in other sectors



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Preliminary data are shown for 1979-80 and estimates for 1981.
REFERENCE: Appendix table 4-9.

Science Indicators—1980

share has increased steadily since then, to 3.7 percent in 1978 and 1979. Traditionally, nonprofit institutions used to receive more R&D money from industry than universities did—50 percent more in 1970. Since then, however, there has been a strong shift in favor of universities, which now receive the larger amount.

Research Publications with Industry and University-Industry Authorship

Publication in technical journals is a standard means for researchers to lay claim to the results of their efforts. Thus, counts of industry-generated publications can serve as indicators of the amount of successful research, in terms of meeting the standards of refereed journals, being done in the industry sector, at least in those areas that companies consider suitable for public disclosure.[69] In addition, personal collaboration between industry and university researchers can be represented by the number of articles jointly authored by researchers in the two sectors. Such joint authorship is one means for sharing scientific and technical information between the sectors.[70]

Industry's share of all journal articles written by Americans was 9 percent in 1979, down from 11 percent in 1973.[71] These publications are concentrated in a few fields. Industry published 36 percent of all U.S. engineering and technology articles in 1979, though the number of these industry articles (in a fixed set of world-class journals) dropped 33 percent from 1973 to 1979.[72] Industry also published 16 percent of the chemistry articles and 15 percent of the physics articles in 1979. On the other hand, industry published only 3 percent of the Nation's research articles in clinical medicine, biomedicine, biology, and mathematics.

[69]Alternatively, trends in publishing by industry authors may reflect local research practices, the number of programs concentrated on, changing time scales for projects, or increasing maturity of research fields. Development does not usually lead to journal publications. Hence, the data discussed here represent research rather than development.

[70]The industrial use of university research, including university publications, is reviewed in Mary Ellen Mogee, *The Relationship of Federal Support of Basic Research in Universities to Industrial Innovation and Productivity*, pp. 34-37.

[71]By comparison, 43 percent of the Nation's research expenditure was in industry, according to preliminary data from National Science Foundation.

[72]These counts are based on over 2,100 influential journals carried on the 1973 *Science Citation Index* Corporate Tape of the Institute for Scientific Information. While some published articles are not covered by these counts, trends and distributions for these articles represent the most influential published science.

From 1973 to 1979, the number of industry-generated science and technology articles published annually in the same set of world-class journals decreased by 21 percent (see appendix table 4-10). This decrease was considerably above the 4-percent decrease in the publication of such articles by *all* U.S. authors. As the following discussion will show, the drop in industry publishing is mainly in applied research articles in the field of engineering and technology. In terms of these journal publications, therefore, industry has declined in research output more than the rest of the United States.

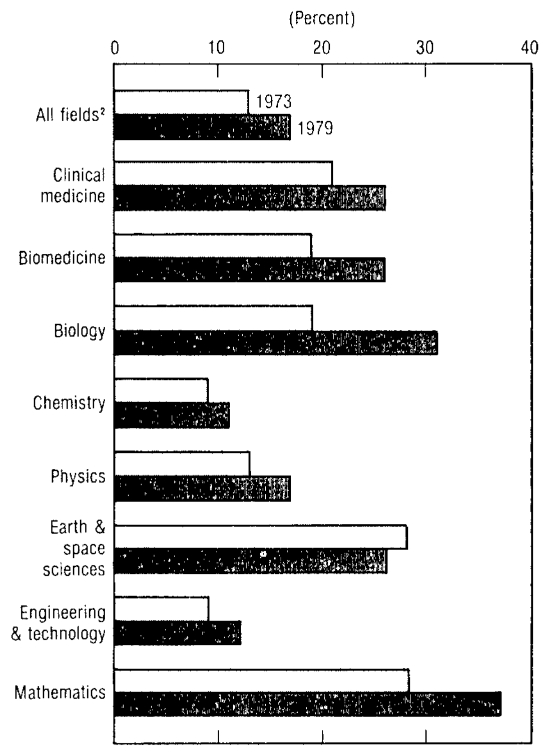
Figure 4-8 shows the portion of all the science and technology journal articles written with industry participation that represent cooperative research with a university researcher. The fraction of cooperatively written articles increased from 1973 to 1979, because the number of coauthored articles increased by 9 percent in spite of a decline in the total number of industry-originated articles (see appendix table 4-10). This coauthorship is greatest, in percentage terms, in mathematics and biology. The fields with the greatest total industry publishing, i.e., engineering and technology, physics, and chemistry, have the lowest share of such joint authorship. Mathematics and biology also are the fields showing the largest percentage increases in joint authorship from 1973 to 1979. The table also shows a general percentage increase in joint publication in the other two life sciences. By these measures, therefore, the part of industry's research that is done cooperatively with universities increased from 1973 to 1979, particularly in mathematics and biology. In terms of actual counts of articles, jointly authored articles increased by 45 percent in biology, 33 percent in physics, and 32 percent in biomedicine.

Appendix table 4-11 shows trends in coauthorship between industry and all other sectors. Again, from 1973 to 1979 there was an increase in the number of coauthored articles, while the total number of articles with industry authors decreased. The fraction of articles coauthored between sectors thus increased, from 22 to 30 percent. Since 60 percent of these coauthored articles involve university coauthors, academia is the outside sector that industry researchers most often choose for research collaboration. This is particularly true in mathematics, where over 90 percent of industry articles coauthored with another sector involve university coauthors. On the other hand, in engineering and technology only 48 percent of industry's intersectoral publications have university involvement.

Insight into the character of industry and joint university-industry research publications is obtained by dividing them into basic and applied research, as on figure 4-9.[73] For comparison, the figure also shows the percentage of all articles published by Americans in 1979 that reported basic research, for a number of research fields. In most fields, industry authors publish a lower share of basic research articles than do all U.S. authors. This is consistent with industry's emphasis on applied research (see figure 4-3). In clinical medicine, however, industry authors published a larger share of basic research

[73] The distinction between basic and applied research is based on the journal in which the publication appears. Each journal on the Institute for Scientific Information tapes is classified by level. Levels 1 and 2 are considered basic research journals; levels 3 and 4 are considered applied. See Mark Carpenter, *International Science Indicators—Development of Indicators of International Scientific Activity Using the Science Citation Index* (Cherry Hill, N.J.: Computer Horizons, Inc., 1979), pp. II-49 through II-51.

Figure 4-8
Portion of all journal publications[1] written with industry participation that are co-authored with universities



[1] Includes the articles, notes, and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. For the size of this data base, see appendix table 1-12.

[2] See appendix table 1-13 for a description of the subfields included in these fields.

REFERENCE: Appendix table 4-10. Science Indicators—1980

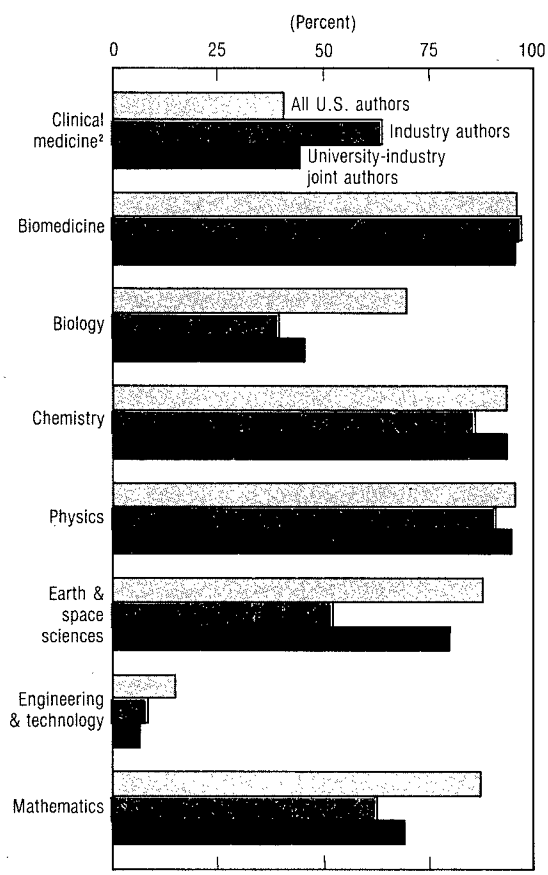
than the national average.[74] The proportions have not changed greatly since 1973. However, industry authors in the earth and space sciences published a higher share of basic research articles in 1973 than in 1979, 64 percent. From 1973 to 1979, there was a notable decrease in the number of applied research articles published in engineering and technology. For all U.S. authors, the number dropped by 30 percent from 1973 to 1979, while for industry authors it dropped 36 percent. Thus, 69 percent of the drop from 1973 to 1979 in all industry-originated articles published annually was due to the drop in applied engineering and technology articles.

The other comparison to be made is between all articles written with industry participation and those with industry-university coauthorship. Figure 4-9 shows that there is a slightly higher level of basic research in the papers coauthored between sectors. This is particularly true in earth and space sciences and, to a lesser extent, in chemistry. On the other hand, clinical medicine is again unusual in having a lower percentage of basic research in university-industry articles than in all articles written with industry participation.

[74]Computer Horizons, Inc., unpublished data.

Figure 4-9

Basic research publications as a percent of all research journal publications[1] by various groups of authors, by field: 1979



[1]Includes the articles, notes, and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. For the size of this data base, see appendix table 1-12.

[2]See appendix table 1-13 for a description of the subfields included in these fields.

REFERENCE: Appendix table 4-12. Science Indicators—1980

Citations Between Industry and University Publications

In addition to published articles, citations are an important means of assessing the transfer of information between universities and industry. Citation counts are based on the assumption that the number of citations to a published article in later published articles is an indicator of the influence or impact of the original article.[75] Moreover, the extent of citation of papers written in one sector by papers written in another is an indicator of the extent to which the citing sector depends on research done in the cited sector.[76]

Table 4-4 shows some results for citations between articles written in industry and articles written in universities. Each number shown represents the citations that one sector makes to another, divided by all the citations it makes to all sectors, and corrected for the number of papers available for citing from each cited sector. Thus, a ratio of 1.00 for university citations to industry papers in biology in 1973 would mean that industry's share of all citations from university authors in that field is equal to industry's share of all 1973 articles published in biology.

[75]Thus citation counts provide a way of weighting publication counts so as to allow for the varying quality of different publications. Since citations in turn do not all have equal significance, they provide a better approximation to quality, but do not measure it exactly.

[76]Citation between sectors and between industrial companies is discussed in Henry Small and Edwin Greenlee, *A Citation and Publication Analysis of U.S. Industrial Organizations* (Philadelphia: Institute for Scientific Information, January 1979).

Recent studies have also explored the references in granted patents to the journal literature. See Mark P. Carpenter, Martin Cooper, and Francis Narin, "Linkage between Basic Research Literature and Patents," *Research Management*, vol. 23 (March 1980), pp. 30-35; Mark P. Carpenter and Francis Narin, *Utilization of Scientific Literature by U.S. Patents* (Cherry Hill, N.J.: Computer Horizons, Inc., November 30, 1978).

Table 4-4. Relative citation ratios[1] by field for citations between industry- and university-originated journal publications[2]

Field[3]	1973	1977
Citations from university to industry:		
Clinical medicine	.57	.50
Biomedicine	.62	.67
Biology	.57	.47
Chemistry	.37	.40
Physics	.67	.58
Earth and space sciences	.54	.37
Engineering and technology	.45	.39
Mathematics	.74	NA
Citations from industry to university:		
Clinical medicine	.72	.51
Biomedicine	.71	.67
Biology	.76	.49
Chemistry	.55	.62
Physics	.47	.45
Earth and space sciences	.74	.71
Engineering and technology	.56	.46
Mathematics	.68	NA

[1]A citation ratio of 1.00 would mean that the cited sector received a share of citations equal to its share of published articles. A lower ratio indicates that articles from the cited sector are cited less often than their numbers would warrant. For example, industry's clinical medicine articles published in 1973 received a share of citations from subsequent university articles that was 57 percent of industry's share of all clinical medicine articles published that year.

[2]Includes the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate tapes of the Institute for Scientific Information.

[3]See appendix table 1-13 for a description of the subfields included in these fields.

REFERENCE: Appendix table 4-13.

Science Indicators—1980.

Since all ratios are less than 1.00, the table makes it clear that the citation between these sectors is less in all fields than would be expected from the number of articles available to cite and the amount of citing done by the citing sector. This result is consistent with the fact that every sector concentrates its citations on its own publications.[77] Furthermore, in almost every case there is a decline in the relative citation ratios between sectors from 1973 to 1977 publications. Chemistry alone shows small increases in citation in both directions. Especially large drops are seen in industry-to-university citing in biology and in clinical medicine and in university-to-industry citing in earth and space sciences. Thus, by this measure university-to-industry transfer of information decreased from 1973 to 1977, particularly in these three fields.

It seems that industry depends more on universities than vice versa. For 1973 publications, at least, the industry-to-university citation ratios were considerably above the university-to-industry ratios in five of the eight fields shown. However, the picture was less clear for 1977, when industry citation to university was dominant in only two fields, while university citation to industry was dominant in one. Physics is the one field in which universities have relied more on industry throughout this period, while industry has had a one-sided and continuing dependence on universities in chemistry and in earth and space sciences.

OUTPUTS OF INDUSTRIAL R&D

Levels of R&D activity can be represented by indicators of R&D inputs, mainly expenditures and personnel. However, for policy purposes it is at least as important to estimate the products and levels of output from this activity. The success of

[77]Computer Horizons, Inc., unpublished data.

the industrial R&D effort is shown by these products rather than by the levels of activity, and it is in these terms that the relative position of the United States in world science and technology must be assessed. Unfortunately, there are considerably fewer standard data series in the output area than there are for inputs.

One essential problem that remains to be solved has to do with the relative quality of outputs. All output indicators are counts of some underlying unit, such as patents. However, not all instances of this counting unit are considered equally valuable. Specifically, not all patents are equally significant, technically or economically. Thus, ways are sought to apply some weight to the units (such as a dollar value for each patent) to account for their differing values.[78] The search for the elusive uniform unit of value is a characteristic problem in the development of both input and output indicators.

This chapter presents indicators for a limited range of industrial R&D outputs. Contributions to scientific and technological knowledge, as represented by journal publications, were discussed in the preceding section. In this section, the production of technical inventions is represented by rates of patenting. Another approach to measuring new technology is to develop parameters describing the capabilities of technologies in use, as these develop over time. Some indicators developed by this new method are also presented. Finally, productivity in the various manufacturing industries is discussed. While productivity is affected by many factors besides R&D, the fact remains that advances in technology are very important to productivity and that productivity improvements are a major goal of R&D. Future work, it is hoped, will add to this list of output indicators.

Patented Inventions

In the industrial context, technical inventions, i.e., new or improved products or processes with some prospective utility, are one of the main results of R&D. Since inventions are often, though not always, patented, patent counts make it possible to estimate levels of technical invention. As a result, these counts also serve as one indicator of the output or level of accomplishment of industrial R&D.

An invention is not itself an innovation, but is a technical achievement on the way to the possible commercial introduction of an innovation.[79] As such, inventions constitute a pool of possible future innovations. Patents, therefore, are not the ultimate measure of innovation, but they do represent the level of proprietary technology available for marketable goods and services.[80] They provide the most useful, systematic, and comprehensive set of information about inventive activity available over a long period.[81]

However, patent counts have certain defects when used to measure levels of technical invention.[82] Some important inventions, and even some areas of technology, are not patented. Also, all patents do not represent equally important inventions, either technically or commercially. This means that aggregate trends in patent numbers may not be an accurate reflection of the trends in really important individual inventions.[83] Nevertheless, patents make it possible to count inventions in the *aggregate*, and they provide the best information available about overall trends in inventive output. In this way they help to show the level of technical invention occurring in the United States, in comparison with the past and with inventive output in other countries.

Inventors and Owners of Inventions Patented in the United States. Figure 4-10 shows the number of patents granted in the United States to both U.S. and foreign inventors. In terms of grant date, year-to-year trends are quite irregular, but there is a clear upward trend from 1960 to the early 1970's, with a drop thereafter. This drop is due to a decline in patents granted to U.S. inventors, at the same time that foreign patenting increased. From 1968 to 1978, foreign patenting in the United States increased at an overall smoothed average rate of 9.6 percent per year, while U.S. domestic patenting

[78]Going a step further, one can observe that the ultimate social benefits of patents or of science and technology in general may not be expressible in dollar terms. It is not clear that any units can be found in which to express those benefits.

[79]Irwin Feller, "The Measurement of Industrial Innovation," *Papers Commissioned as Background for Science Indicators—1980*, vol. IV, National Science Foundation, 1981, pp. 6-12.

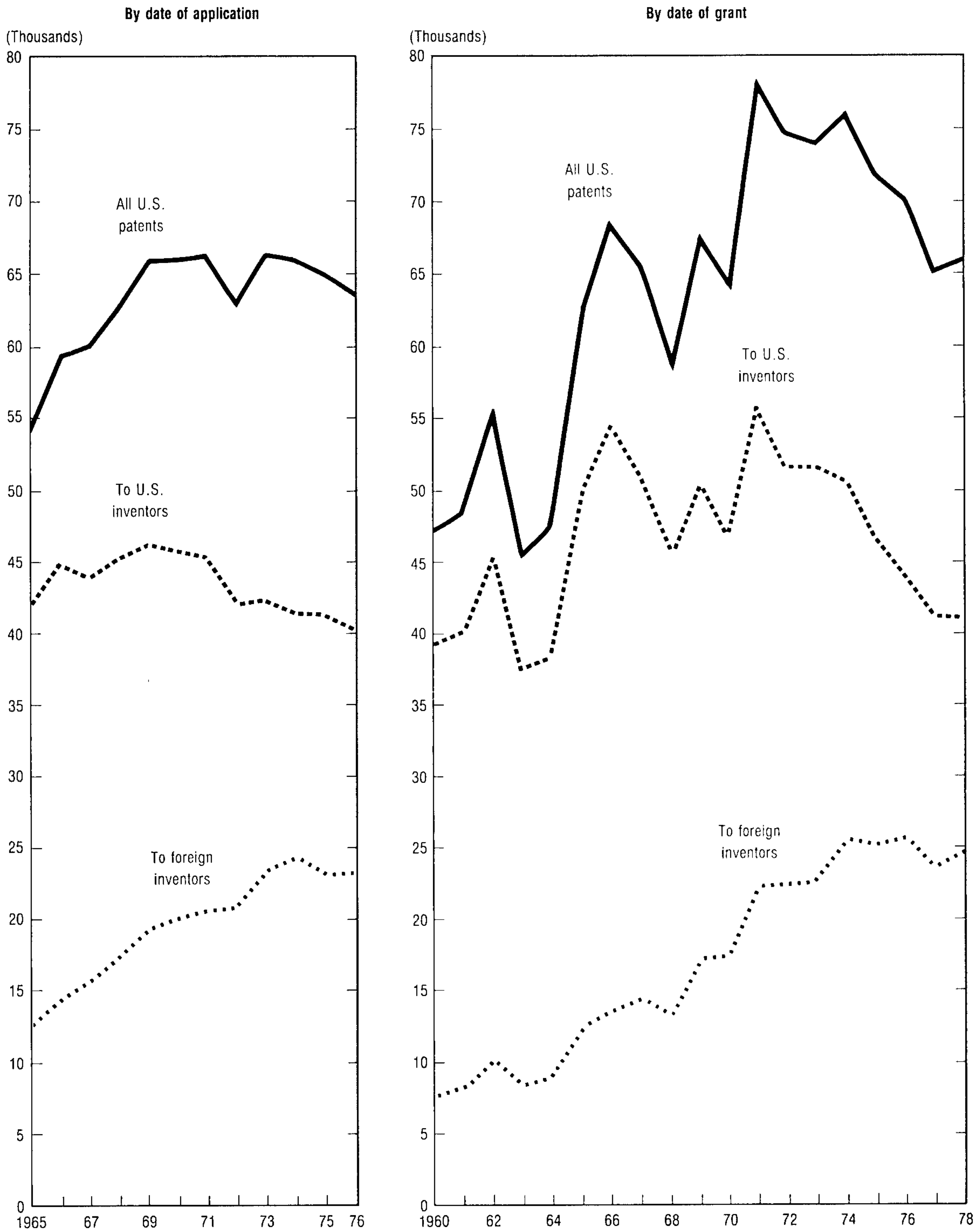
[80]Edward E. David, Jr., "Industrial Research in America: Challenge of a New Synthesis," *Science*, vol. 209 (July 4, 1980), p. 137.

[81]Christopher Freeman, "The Determinants of Innovation: Market Demand, Technology, and the Response to Social Problems," *Futures* (June 1979), p. 209.

[82]For a more thorough discussion of the uses and limitations of patenting data, see *Science Indicators—1978*, National Science Board (NSB 79-1), pp. 99-102, and also *The Meaning of Patent Statistics*, National Science Foundation, 1979.

[83]Freeman, p. 210.

Figure 4-10
U.S. patents granted, by nationality of inventor



REFERENCE: Appendix table 4-14.

Science Indicators—1980

declined slightly on the average.[84] From 1971 to 1978, U.S. patenting by American inventors declined by 2.3 percent per year. While foreign patenting was only 16 percent of all patenting in the United States in 1960, it rose to 38 percent in 1978 and in 1979.[85] On the other hand, the number of U.S. patents issued to foreigners has not gone up appreciably since 1974.

One reason for the considerable irregularity in patent counts by date of grant is that the Patent and Trademark Office does not process its backlog of applications at a constant rate. To remove the effect of these delays and irregularities, figure 4-10 also shows counts of granted patents according to date of application. The date of application is a better representation of the actual date of invention. The data are much smoother in this case but cover fewer years. For American inventors, the decline in successful applications began in 1970. Successful foreign applications increased steadily from 1965 or earlier to 1974. Since then, there has been no evident increase.[86]

The increases observed in foreign patenting in the United States could indicate a growth in foreign rates of invention. However, this is unlikely in view of the fact that foreign domestic patenting did not increase in the same way.[87] In fact, most of the foreign countries significantly involved in patenting in the U.S. (with Japan a major exception) experienced a decline in domestic patenting beginning in the middle or late 1960's.[88] Since most national patent offices issue more patents to foreigners than to citizens of their own country, the United States is only approaching the situation observed elsewhere in the world. Of course, this is not necessarily beneficial to the United States if it suggests an increasing penetration of U.S. markets by foreign manufacturers.[89]

The drop in U.S. domestic patenting probably indicates a decline in the rate of production of inventions by Americans. It parallels the decline in constant-dollar R&D expenditures in U.S. industry that began in 1970 (see figure 4-1).[90] Moreover, the drop in patenting occurs in approximately 48 out of 55 product fields.[91] This suggests that the drop is not a peculiarity of the practices in a few industries, such as a decreasing tendency to patent the inventions produced in certain technologies, but is due to a phenomenon common to most industries.[92]

The patents granted to U.S. inventors can be further classified according to whether they belong to domestic corporations or to other owners (see figure 4-11). Patents are assigned to corporations or the Government by employee inventors, while self-employed inventors usually retain title to their patents at the time they are granted. The figure shows a low level of patent ownership by the Government.[93] U.S. individuals have had a very steady

[84] The rate of increase or decrease used here is the constant annual increment that would give the same total patenting as actually occurred in the 1969-78 period, divided by the 1968 patenting taken as a three-year average. See appendix table 4-17. Over the longer interval from 1963 to 1976, foreign patenting in the U.S. increased by an average of 14.7 percent per year.

[85] Patent counts for 1979 are unreliable because the Patent and Trademark Office did not have enough money in that year to print and issue all approved patents. However, ratios should be sufficiently reliable, since patents were printed and issued as usual in the order in which they were approved, with no special selection of those to be issued.

[86] Since not all applications from these years have been processed, counts for the most recent years shown are probably low by several percent from their ultimate values.

[87] However, some investigators suggest that for some countries foreign patenting is a more reliable proxy for that country's technological output than is domestic patenting. See Luc Soete, "The Impact of Technological Innovation on International Trade Patterns: The Evidence Reconsidered," paper prepared for the Organisation for Economic Co-operation and Development Science & Technology Indicators Conference, Paris, September 15-19, 1980, p. 24.

[88] *Industrial Property*, annual December issues (Geneva: World Intellectual Property Organization).

[89] Foreign patenting is discussed at greater length in the chapter on International Science and Technology.

[90] The relation of R&D expenditures to patenting is discussed in Keith Pavitt, "Using Patent Statistics in *Science Indicators:* Possibilities and Problems," in *The Meaning of Patent Statistics*, National Science Foundation, 1979. A linear correlation has been found between patenting rates in individual lines of business and R&D expenditures, if differences in the industry of origin are taken into account. See Scherer, p. 20.

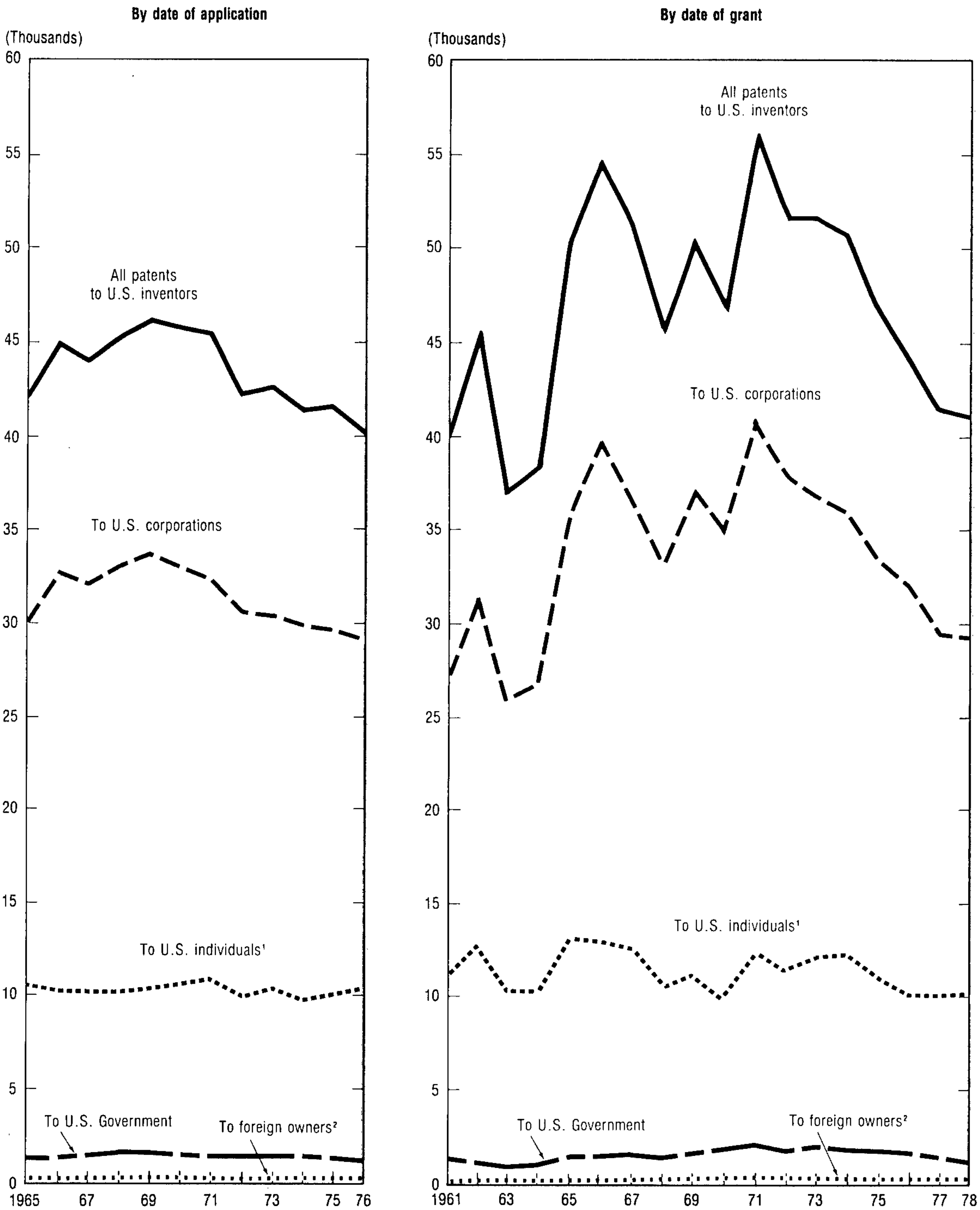
[91] U.S. Patent and Trademark Office, Office of Technology Assessment and Forecast, *Indicators of the Patent Output of U.S. Industry, IV* (July 1980). The exceptions are aircraft, engines and turbines, drugs, soap, agricultural chemicals, and possibly petroleum and plastics.

[92] The U.S. decline parallels the earlier decline of domestic patenting in other countries. (Unlike the U.S. data, the foreign patenting discussed here is expressed in terms of raw applications. However, in those terms, U.S. domestic patenting still shows a decline beginning in 1970. See *Industrial Property*, annual December issues (Geneva: World Intellectual Property Organization)). This again suggests a common explanation, namely a decline in invention. (The use of domestic patenting as a measure of the inventive output of a country is illustrated by Dennis Schiffel and Carole Kitti, "Rates of Invention: International Patent Comparisons," *Research Policy*, vol. 7 (1978), pp. 324-340.)

[93] Because patents owned by the Government tend not to be exploited commercially, P.L. 96-517, recently enacted, permits nonprofit organizations and small business firms performing federally supported R&D to retain the patent rights to any inventions resulting from that R&D. See *Patent Policy*, hearings before the Subcommittee on Science, Technology, and Space of the Committee on Commerce, Science, and Transportation, United States Senate, July 23 and 27, October 25, 1979, and January 25, 1980.

Figure 4-11

U.S. patents granted to U.S. inventors, by type of owner



[1] Includes unassigned patents.

[2] Comprises patents assigned to foreign corporations, governments, and individuals.

REFERENCE: Appendix table 4-15.

Science Indicators—1980

Table 4-5. Ownership of U.S. patents due to U.S. inventors, by product field: 1978[1]

Product field	Percent of patents in each product field
Highest share owned by U.S. corporations:	
Industrial organic chemicals	94
Plastics materials and synthetic resins	92
Agricultural chemicals	92
Drugs and medicines	92
Soaps, detergents, and cleaning preparations, perfumes, cosmetics, and other toilet preparations	91
Highest share owned by U.S. Government:	
Ordnance, except missiles	27
Guided missiles and space vehicles and parts	17
Highest share owned by U.S. individuals[2]:	
Ship and boat building and repairing	47
Farm and garden machinery and equipment	43
Aircraft and parts	41
Engines and turbines	39
Motor vehicles and motor vehicle equipment	39

[1]Date of patent grant.
[2]Includes unassigned patents.

REFERENCE: Appendix table 4-16.

Science Indicators—1980.

level of patenting.[94] The drop in U.S. patented inventions is evidently due to a drop in patents owned by corporations. From 1971 to 1978, corporate patenting declined about 2.9 percent per year on the average. In terms of application date, the decline in corporate patenting started in 1970, as did the decline in all U.S. domestic patenting.

Patent Grants by Product Field. The classification system used by the U.S. Patent and Trademark Office places a patent into one of approximately 100,000 possible classes on the basis of the type of material, device, or process that it represents.[95] Since these classes depend more on the way the invention is built and operated than on its economic use, they are not suitable for studying levels of invention in various areas of technology. For this reason, the Patent and Trademark Office, with NSF sponsorship, has developed a concordance that assigns each patent class to one or more classes of the Standard Industrial Classification (SIC) system for industries and products. The assignment is based on the judgment of Patent and Trademark Office personnel as to the type of establishment that would produce the kind of product or apparatus represented by that patent classification or would carry out the process steps included in the patent classification.[96] By using the concordance, the patents applied for or granted in any year can be reclassified in terms of the SIC.[97]

The ownership of patents in different product fields reflects differences in the technologies themselves and in market conditions for them. Most patents granted to Americans are owned by corporations, but the level of corporate ownership varies significantly from one product field to another. As table 4-5 shows, corporate ownership is especially

[94]Patenting by individuals ultimately makes important contributions to industrial technology. See the statements by Jacob Rabinow in *Patent Policy*, hearings before the Subcommittee on Science, Technology, and Space of the Committee on Commerce, Science, and Transportation, United States Senate, Part 1, July 23 and 27 and October 25, 1979.

[95]There are also cross-references to other patent classes, but these are not involved in the data discussed here.

[96]*Technology Assessment and Forecast: 6th Report*, U.S. Patent and Trademark Office, Office of Technology Assessment and Forecast, 1976, p. 158.

[97]About 94 percent of patents for inventions can be reclassified in this way. A single patent can be assigned to more than one SIC class and therefore can be counted more than once. However, no aggregate totals are inflated by this multiple counting. The result is that patent counts in subclasses will often add to an aggregate total greater than the correct total shown for that aggregate.

Table 4-6. Average annual change in patent grants to U.S. inventors, for product fields with the greatest changes: 1968-78

	Percent change per year
Product fields with largest increases:	
Soaps, detergents, and cleaning preparations, perfumes, cosmetics, and other toilet preparations	8.7
Agricultural chemicals	7.4
Drugs and medicines	6.0
Professional and scientific instruments	3.0
Food and kindred products	2.8
Aircraft and parts	2.2
Stone, clay, glass, and concrete products	2.2
Product fields with largest decreases:	
Household appliances	−3.6
Electrical industrial apparatus	−3.4
Guided missiles and space vehicles and parts	−3.2
General industrial machinery and equipment	−2.4
Electrical transmission and distribution equipment	−2.1
Electrical lighting and wiring equipment	−2.1

REFERENCE: Appendix table 4-17.

Science Indicators—1980.

high in the chemical technologies. In these industries, R&D is supported more by private than by Federal funding, so that Federal ownership is low. At the same time, patented inventions in these fields are so technical and so expensive to develop and market that they do not have a high level of individual ownership.

Government ownership of patents is not very high in any product field, but it is highest in those where R&D is largely done under Government contract and the technology is developed for Government purchase. For example, overall levels of patenting in both ordnance and missiles and spacecraft are low, although the latter field has a high level of R&D expenditure.[98] Patents owned by individuals are largely in the mechanical technologies, where development of improvements is within the resources available to individuals. As with all patented inventions, these inventions when used are ultimately used in industry, whether by licensing, outright sale, or entrepreneurial exploitation by the inventor.

From 1968 to 1978, the rate of patent grants to Americans declined slightly. However, the experience during this period was markedly different from one product field to another. As table 4-6 shows, there were remarkable annual increases in some fields, mainly in chemical technologies. For example, in agricultural chemicals there has been rapid increase in the patenting of pesticide compounds.[99] Drugs and medicines has seen very fast growth in prostaglandins and their derivatives. In most product fields, there was a slight decrease in annual patenting (appendix table 4-17), but the decrease was especially great in a few fields, notably in the electrical and mechanical technologies.

Short-term trends should be used with caution because of the year-to-year fluctuations in the data, but some notable trends did emerge in the last few years. Overall patenting by U.S. inventors dropped about 4 percent per year from 1976 to 1978, but patenting in petroleum and natural gas rose by 15 percent per year.[100] There were also large increases in agricultural chemicals, plastics and resins, and electrical lighting and wiring equipment. On the other hand, patenting in soap and cosmetics and in food, which rose substantially in the total 1968 to 1978 period, dropped by 17-18 percent per year from 1976 to 1978. Other large decreases occurred in miscellaneous chemicals, primary metals, and motorcycles and bicycles.

[98]See appendix table 4-17 and *R&D in Industry, 1977*, National Science Foundation (NSF 79-313), p. 54.

[99]U.S. Patent and Trademark Office, Office of Technology Assessment and Forecast, *Indicators of the Patent Output of U.S. Industry, IV* (July 1980).

[100]U.S. Patent and Trademark Office, Office of Technology Assessment and Forecast, special tabulations.

Table 4-7. U.S. patenting in energy technologies

Technology	Energy patents granted to U.S. inventors: Patents in 1978	Energy patents granted to U.S. inventors: Average annual percent change[1] (1973-78)	Percent of all energy patents to foreign inventors (1978)
All energy technologies	3,727	0.3	35.8
All nuclear	203	1.2	37.7
Fission	129	1.3	41.4
Fusion	12	−8.0	20.0
Solar	360	93.7	16.7
Tide, wave, and current	23	41.4	25.8
Wind	37	56.2	13.9
Geothermal and other natural terrestrial heat	32	84.8	8.6
Synthetic fuels	306	14.2	28.0
Fossil fuels	953	−3.9	25.2
Energy recovery—mines	44	9.5	65.9
Energy recovery—wells	486	−3.3	16.9
Space heating and cooling	557	8.5	20.8
Electric power	929	−2.2	38.7
Other energy generation	493	4.8	57.3
Energy conservation	208	2.4	40.6

[1]Calculated by the method of appendix table 4-17.

SOURCE: Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, *Energy Patenting (1963-1979)*, August 1980.

Science Indicators—1980.

Patenting in Energy-Related Technologies. Since the 1974 Arab oil embargo, an ever-growing portion of industrial research activity has been directed to the energy field. Potential scarcity and rising prices have made projects that once seemed far-fetched suddenly attractive, and a number of companies are investing a big portion of their R&D funds in pursuing them.[101] The scope and direction of U.S. efforts in energy has become a major policy issue.

The level of patenting in energy-related technologies is one indicator of the success of this effort. A new concordance makes it possible to correlate energy-related Patent Office classes with specific energy technologies.[102] Thus, the energy areas that are growing rapidly or receiving special attention can be shown (table 4-7). Of the 41,233 patents granted to Americans in 1978, 3,727 (9 percent) were energy-related. Their distribution among corporate, Government, and individual owners is very similar to that of total patenting in 1978.[103] Similarly, the share of energy-related patents going to foreigners is close to the 38 percent for all patents in 1978.

However, there are considerable differences between technologies.[104] The greatest output of patents by far is in fossil fuels and in electric power.[105] These areas have also seen declines like the general decline in U.S. patenting during this

[101]Niles Howard and Susan Antilla, "U.S. Innovation: It's Better than You Think," *Dun's Review* (March 1979), p. 57.

[102]A few Patent Office classes, such as gas solidification and liquefaction, are not obviously energy-related and therefore are excluded. A small number of patents in these excluded areas may, in fact, be energy related.

[103]Thus, in 1978 and 1979, 72 percent of these patents belonged to corporations, 4 percent to the Government, and 23-24 percent to individuals. See U.S. Patent and Trademark Office, Office of Technology Assessment and Forecast, *Energy Patenting (1963-1979)*, report prepared for the National Science Foundation, Science Indicators Unit (August 1980); cf. appendix table 4-15.

[104]Since a patent can fall into more than one category, the patents in individual technologies add up to more than the total number of patents.

[105]This category includes all nonnuclear generation of electrical energy by power plants.

period. However, electric power includes promising new technologies, such as the sodium-sulfur battery, which will allow electric utilities to store excess power during periods of low demand for use during peak periods. While 75 percent of fossil-fuel patents went to Americans, 88 percent of these belong to U.S. corporations. Thus, this activity seems to be especially concentrated in American corporations. Important activities include efforts to convert coal into cleaner-burning or more easily transportable fuel in liquid or gaseous form.

By contrast with fossil fuels, Government ownership is especially high in the nuclear area. In this case, the patent counts are unrealistically low, because many inventions in this area are classified as secret and kept in a confidential file in the Patent Office.

In some relatively small fields, growth since 1973 has been remarkably rapid. The outstanding instance is solar energy. In this technology, foreign patenting is especially low. In addition, there is an unusual distribution of ownership of U.S.-originated patents, with 51 percent of patents in this area belonging to individuals.[106]

In the solar energy field, there has been especially high activity in recent years in solar heat collectors. Another rapidly growing technology is power plants using natural heat. In fossil fuels, the most rapidly growing areas have been catalytic processes for removing sulfur from petroleum and catalytic reforming of oil stocks.

Composite Measures of Technology

Much of industrial R&D is directed to improving the technical quality of industrial and consumer products, i.e., their ability to perform the functions for which they are purchased. Thus, any obtainable measures of the technological improvement of various products and industrial processes over time could serve as indicators of the success of industrial R&D in those technical areas. Such indicators would supplement patenting indicators, which represent inventions not yet in use, as well as economically based indicators such as productivity, which reflect many influences in addition to technology.

At present, the development of indicators of this kind is in its infancy. However, some early results are available. One method involves tracing over time certain variables that represent good or bad features of a given technology (for example, see figures 4-12 and 4-14). Several such variables are then combined algebraically to produce a composite index that represents the improving overall state of development of each technology over time (figures 4-13 and 4-15).[107] This procedure has all the difficulties inherent in making widely acceptable assessments of quality.[108] Still, it opens up new possibilities for the measurement of technological innovation.

Two technologies will serve to illustrate this method: computers and antibiotics. Figure 4-12 represents one variable applicable to computer technology, the number of addition commands (including memory accesses) that the various computers represented can perform in 1 second. The data points represent the best computer, in terms of this variable, that was introduced to the market in each year.[109] Figure 4-13 shows the composite index for computers. The index is a combination of three variables for each individual computer: computer speed (itself a composite of addition rate and other processing speeds), cost per operation, and memory capacity.[110] The data points represent individual computers in terms of their date of market introduction. Only computers that have a higher index value than any previously introduced computer are shown. Thus, the figure shows the highest technical level attained by commercially available computer technology in each year. The figure is drawn on a semilogarithmic scale to bring out the small changes in the index in the earlier years, which are still large percentage increases over previous technology.

The so-called first generation of computers extended from 1951 to about 1959. They used vacuum tubes rather than transistors, and differed from each other mainly in their storage media. While the earliest ones used a mercury delay line memory, later models employed a magnetic drum system,

[106] *Energy Patenting (1963-1979)*, U.S. Patent and Trademark Office, Office of Technology Assessment and Forecast, 1980. See appendix table 4-15.

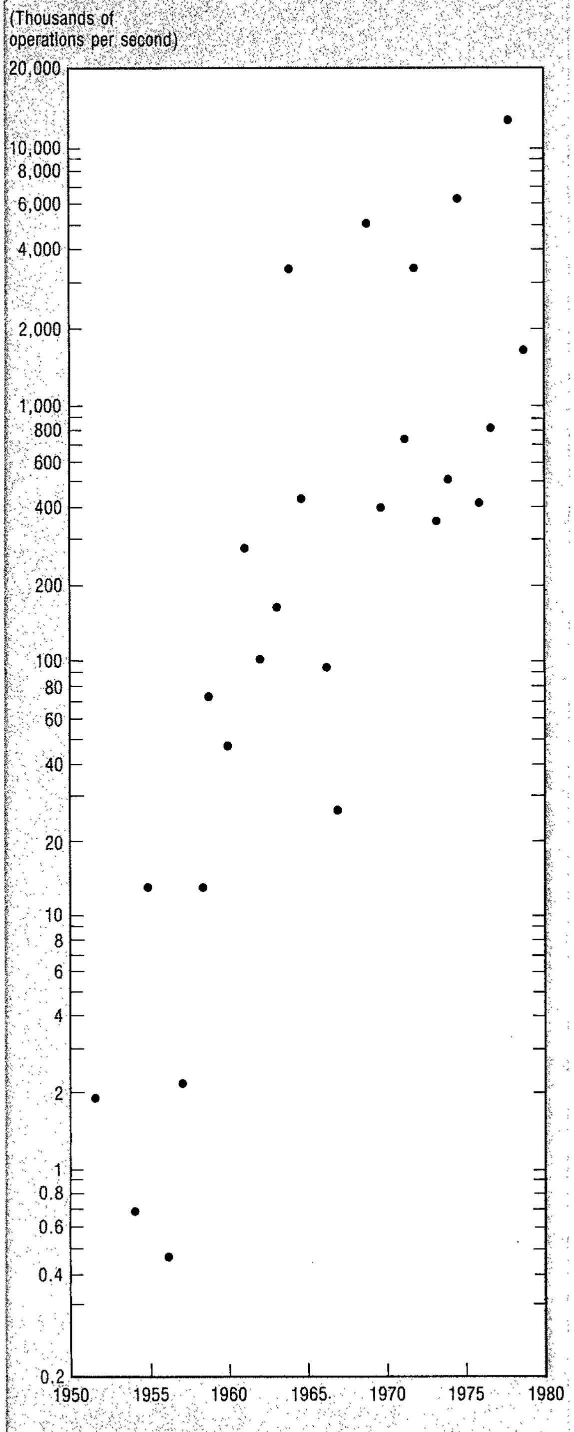
[107] This procedure involves assigning each variable a relative weight, which is fixed by a small panel of experts. Experience has shown that in the present examples the results are insensitive to the exact values of the weights, within a broad range.

[108] See W. Curtiss Priest and Christopher T. Hill, "Identifying and Assessing Discrete Technological Innovations: An Approach to Output Indicators," in *Papers Commissioned as Background for Science Indicators—1980*, vol. IV: The Measurement of Industrial Innovation, National Science Foundation, 1981, especially pp. 9-11. For a general discussion of technology measurement, see Devendra Sahal, "The Generalized Distance Measures of Technology," *Technological Forecasting and Social Change*, vol. 9 (1976), pp. 289-300.

[109] Thus the state of computer technology, as measured by this one variable, is represented by the highest point on the graph up to a given year. Measurement of computer technology is discussed in Montgomery Phister, Jr., *Data Processing: Technology and Economics* (Bedford, Mass.: Digital Press, 1979).

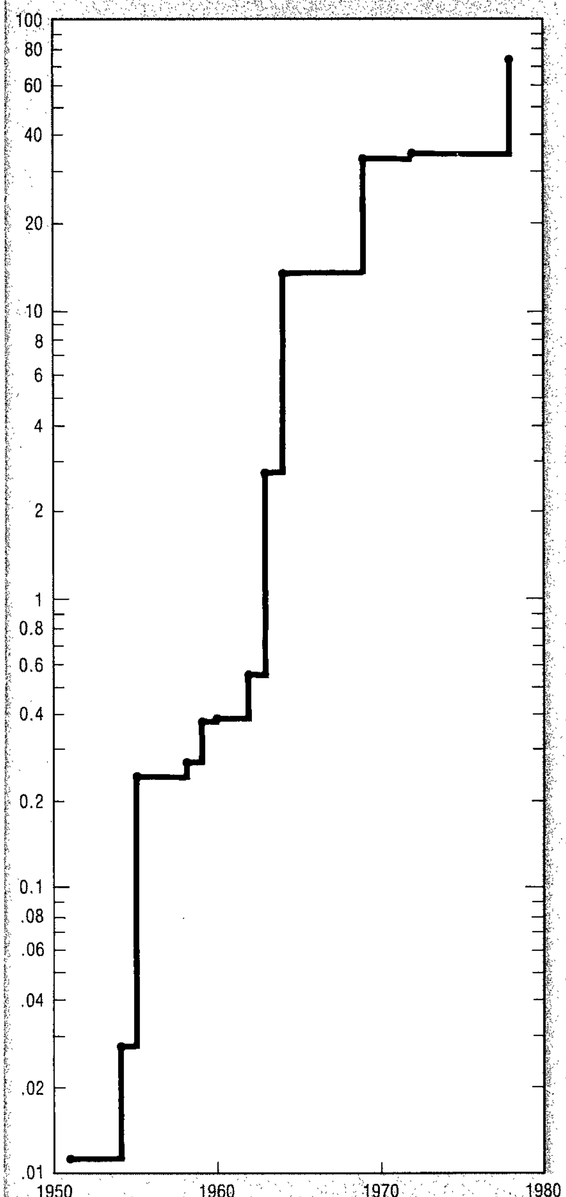
[110] For the equation, see appendix table 4-19.

Figure 4-12
Maximum addition rate for computers introduced in each year



SOURCE: Appendix table 4-18. Science Indicators—1980

Figure 4-13
Computer performance index



SOURCE: Appendix table 4-19. Science Indicators—1980

and ultimately a magnetic core memory.[111] The newer memories were both larger and more rapidly accessed. The second generation of computers, introduced from 1959 to 1963, used transistors and had magnetic core storage systems for main memory. Some also had magnetic drum disks for auxiliary storage memory.

[111]The Futures Group, Glastonbury, Conn., preliminary re port, August 1980.

The third generation of computers, using integrated circuits, appeared in 1964. Further improvements in integrated circuits and memory organization and accessing have continued up to 1978. Considerable advances are still occurring, and there is no evidence that the performance index is approaching a limit.

In the case of antibiotics, the technology is chemical and biological, rather than electronic and mechanical. Still, the same kinds of indices can be developed. Figure 4-14, for example, shows the effectiveness of various antibiotics against a given bacterium and the year of introduction for each. Only the most effective antibiotic introduced in each year is shown. Effectiveness is defined in terms of five characteristics of each antibiotic relevant to controlling this organism. They include "concentration," the in vitro concentration required to inhibit the growth of 75 percent of the organisms, which is a surrogate for the concentration required in the patient's blood to control the bacterium. Biological half-life measures the retention of the antibiotic in the body and thus represents the elapsed time before another dose is required. Other variables represent side effects, ease of administration, and cost. The equation form and weighting coefficients are the same for each bacterium and each antibiotic.[112]

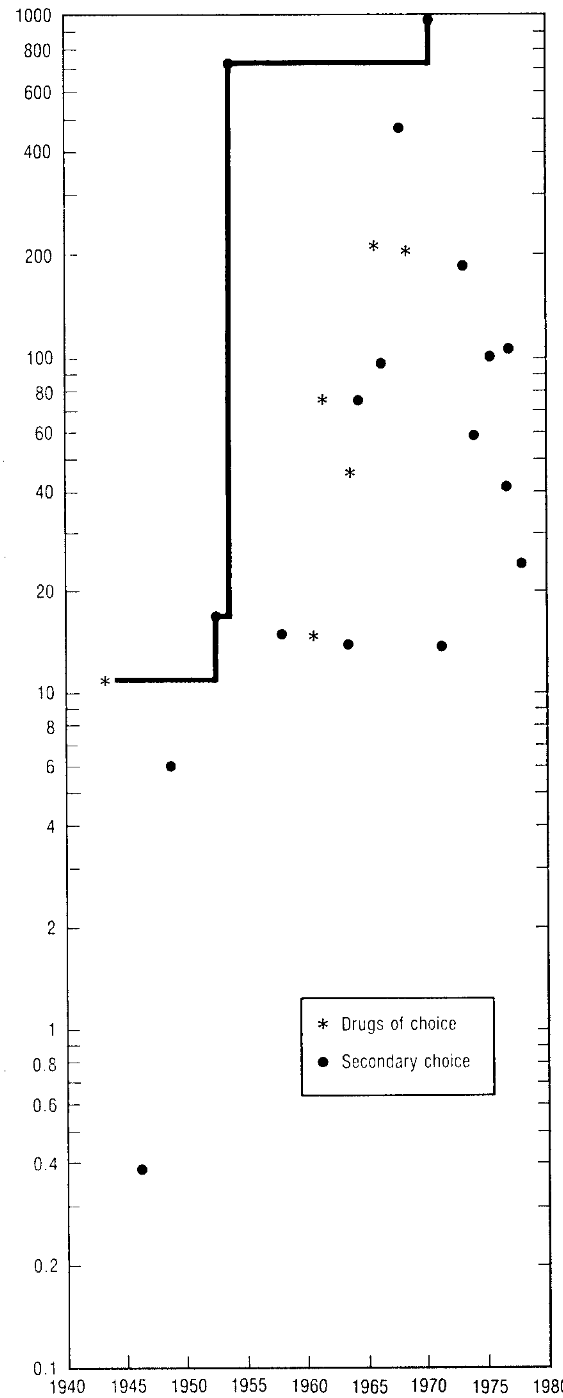
The chart shows the performance of a wide range of antibiotics, including many that were recently introduced but were not developed to deal with this particular bacterium. The chart also shows some of the "drugs of choice" against this particular bacterium.[113] Some of these are not the most effective agents according to this figure. There are two obvious explanations: The medical profession may not judge the quality of an antibiotic according to criteria similar to the index shown on the figure, or it may adhere to older substances after recognizably better ones have been introduced because of familiarity with the older drugs and fear of the effects of unfamiliar drugs.

In this case also, a composite index can be developed showing the state of this technology for any given year. Each point on figure 4-15 represents one antibiotic and its year of introduction. The composite index for that antibiotic is its effectiveness averaged over the whole list of bacterial types, weighted in terms of frequency of appearance in

Figure 4-14

Performance index of various antibiotics against one bacterium, by year of antibiotic introduction

[Staphylococcus Aureus]



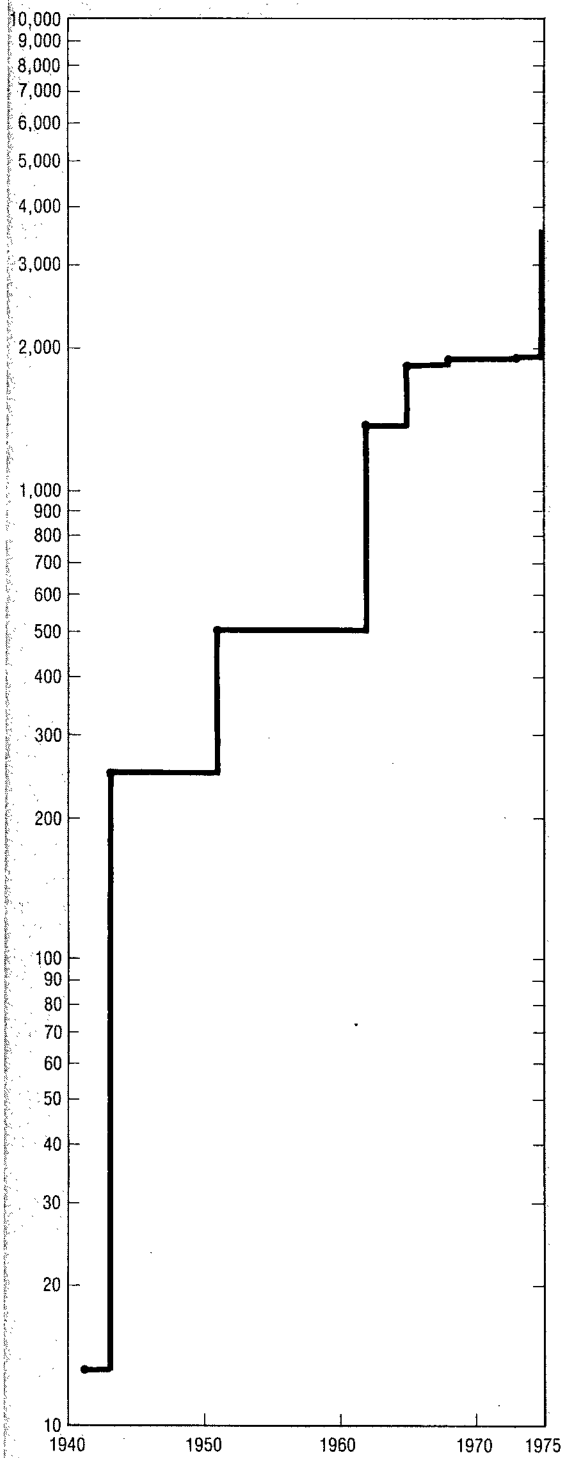
REFERENCE: Appendix table 4-20

Science Indicators—1980

[112]See appendix table 4-20.

[113]Drugs of choice and secondary choices were ascertained from several medical sources; in particular, A. Kucers and N. McK. Bennet, *The Use of Antibiotics: A Comprehensive Review with Clinical Emphasis*, 3rd ed. (Philadelphia: Lippincott, 1978); and *The Medical Letter on Drugs and Therapeutics*, vol. 22 (January 25, 1980).

Figure 4-15
Composite antibiotics performance index



SOURCE: Appendix table 4-21.

Science Indicators—1980

acute care hospitals.[114] Only those antibiotics are shown that have higher index values than any previously introduced antibiotics. Thus, this figure shows the increasing quality over time of antibiotics for clinical use. The greatest breakthrough in the history of antibiotics continues to be the introduction of penicillin in 1943. Penicillin has an index 19 times as high as that of the preceding sulfa drugs. The performance index has not increased by this magnitude since 1943. It is also worth noting that the two antibiotics with the highest performance indices, rosamicin and sisomicin, are not sold in the United States.

Indicators consisting of composite performance measures represent individual technological innovations in terms of their cumulative effect on technological performance. Further development of this very new method will allow it to be applied consistently to a wide variety of other technologies. It may be possible to add together the performance indices for individual technologies to represent large aggregated industries.[115] The policy interest of this method lies in the possibility of comparing performance improvements with inputs to technology, as well as comparing the state of U.S. and in foreign development of the same technology, and showing periods of fast and slow development of a technology in a given country. The pace of development could, in turn, be related to nontechnological events, such as changes in Government policies and in levels of R&D effort.

Productivity

The labor productivity of an industry, company, or nation can be defined as the ratio of its output to the hours of labor that went into that production. Since technological innovation and diffusion is an important contributor to the improvement of productivity, it is worthwhile to consider some existing data on productivity and some situations in which technology has recently affected the productivity picture in various industries.[116] In

[114]About 98 percent of the bacterial cultures encountered in hospitals are covered by this figure.

[115]Figure 4-20 illustrates this possibility, since it aggregates the technologies for killing specific bacteria over all bacteria.

[116]It is common among policymakers to see technological innovation and productivity as closely related issues. See, for example, *Productivity and Technical Innovation*, Hearing Before the Task Force on Inflation of the Committee on the Budget, Subcommittee on Science, Research, and Technology, Committee on Science and Technology, U.S. House of Representatives, July 23, 1979. A general study of the productivity problem, with policy options, is *The Productivity Problem: Alternatives for Action*, Congressional Budget Office, January 1981. Chapter V of that report discusses the relation between technology and productivity. Economists usually make this connection also. See, for example, H. P. Binswanger and V. R. Ruttan, *Induced Innovation* (Baltimore: Johns Hopkins University Press, 1978).

addition, some sources treat productivity as an indicator of technological innovation.[117]

In assessing the relation of productivity to technological innovation, it is desirable to look at the limitations in productivity data[118] and at the many factors, in addition to technology, that influence productivity. Such a discussion will make clear the positive effects of technology on productivity[119] and also will show the dangers involved in using productivity as an indicator of technology in cases where the connection between the two is not understood.[120]

Over all, productivity growth in U.S. industry has slowed rather steadily since 1965. In the nonfarm sector of the private business economy, productivity grew 2.7 percent per year from 1957 to 1965, but it grew only 1.6 percent per year from 1965 to 1973 and only 0.9 percent per year in the 1973-78 interval.[121] Productivity actually declined in 1974, 1978, 1979, and 1980.[122] The decrease from 1978 to 1979 was 0.8 percent, while the decrease from 1979 to 1980 was 0.5 percent. For the manufacturing-industry component of the economy, the average annual growth rate dropped from 3.3 percent in the 1957-65 period to 2.8 percent from 1965 to 1973, and then to 1.7 percent from 1973 to 1978, with an actual decrease in productivity in 1974 and 1980. For 1979, the increase was 1.0 percent, while the 1980 decrease was 0.3 percent.

Individual industries, of course, vary considerably in their productivity trends. Some industries seem to have a definite "productivity problem," while others do not. Table 4-8 shows the trends in labor productivity for 21 manufacturing industries.[123] Since manufacturing productivity peaked in 1957 and 1973, those years are corresponding points in the business cycle, and therefore are chosen as break points for showing productivity changes. Large increases are seen in petroleum, electrical machinery, textiles, and chemicals. A few industries, such as food, apparel, and motor vehicles, actually improved their productivity growth in the 1973-78 period. On the other hand, primary metals shows the greatest drop in productivity performance of all 21 industries. The aircraft industry also shows a strong decline from its 1973 productivity. Generally low productivity improvement is found in furniture; printing; stone, clay, and glass; and fabricated metals.

In the industries with the greatest productivity changes, technology plays a significant role. In the electronic components industry, productivity improvements can be attributed to rapid technological advance.[124] Petroleum refiners have achieved above-average productivity gains since 1957 through automation and economies of scale. Large productivity improvements in chemicals have occurred in synthetic fiber manufacture, in pharmaceuticals, and, in more recent years, in paints and allied products. Many of these improvements are due to process improvements and the automation of large facilities. Similarly, industries like textiles and apparel have been able to introduce high-technology

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[117]Christopher T. Hill, "Technological Innovation: Agent of Growth and Change" in Christopher T. Hill and James M. Utterback (eds.), *Technological Innovation for a Dynamic Economy* (New York: Pergamon Press, 1979), p. 3. Also see Mogee, *Technology and Trade: Some Indicators of the State of U.S. Industrial Innovation*, pp. 24-26.

[118]The limitations in productivity data include the following: In many major areas of public R&D investment, such as defense, space, and health, there is no way to estimate outputs in economic terms except by measuring inputs. Thus any productivity improvements will not show up as increases in the output of these areas, and may even be registered as declines. (See Zvi Griliches, "Issues in Assessing the Contribution of Research and Development to Productivity Growth," *The Bell Journal of Economics*, vol. 10, (Spring 1979), pp. 96-99, 104.) Output of consumer products is measured in terms of price, which often fails to account for improvements in product quality. Moreover, when one industry sells a product to another, changes in price may not fully reflect technical improvements, so that productivity improvements appear to occur in the buying industry that actually are the results of technological improvements in the selling industry.

[119]Jorgensen argues that the fall in the rate of productivity growth from 1973 to 1976 is due to a dramatic decline in the rate of technical change. The rate of technical change in turn is negatively correlated with the effective tax rate on corporate income. See Dale W. Jorgensen, "Taxation and Technical Change," in *Preliminary Papers for a Colloquium on Tax Policy and Investment in Innovation*, National Science Foundation, 1981.

[120]The technological determinants most likely to influence industrial productivity have been listed as: alterations in the design of products; changes in the design and scale of operating processes, facilities, and equipment; improvements in control systems; and modifications in the physical and chemical properties of material inputs, as well as the introduction of new types. See Bela Gold, *Productivity, Technology, and Capital* (Lexington, Mass.: D.C. Heath, 1979), pp. 88-95.

[121]U.S. Department of Labor, Bureau of Labor Statistics, unpublished tabulations.

[122]Ibid. Some of these declines seem to be related to the business cycle rather than to technology specifically.

[123]Productivity here is defined as constant-dollar gross product originating, per hour of production plus nonproduction employee labor. The industries discussed here are at the two- or three-digit SIC level. Data at the four-digit level can be found in *Productivity Measures for Selected Industries, 1954-79*, U.S. Department of Labor, Bureau of Labor Statistics, Bulletin 2093 (April 1981).

[124]Edward Meadows, "A Close-Up Look at the Productivity Lag," *Fortune* (December 4, 1978).

Table 4-8. Labor productivity of manufacturing industries

Industry	Average productivity change (percent per year) 1957-1973	1973-1978
All manufacturing	2.8	1.6
Food and kindred products	2.8	3.9
Tobacco manufactures	4.0	3.3
Textile mill products	4.5	3.9
Apparel and other fabric products	2.8	3.9
Lumber and wood products	4.0	1.4
Furniture and fixtures	1.3	1.7
Paper and allied products	3.6	.1
Printing, publishing, and allied industries	1.8	.5
Chemicals and allied products	4.6	1.5
Petroleum refining and related industries	4.9	2.5
Rubber and miscellaneous plastics products	3.3	.2
Leather and leather products	2.7	1.7
Stone, clay, glass, and concrete products	1.8	1.8
Primary metals industries	.9	−2.7
Fabricated metal products	1.9	.7
Nonelectrical machinery	2.1	− .1
Electrical and electronic machinery, equipment, and supplies	4.7	2.4
Motor vehicles and motor vehicle equipment	3.4	6.2
Aircraft and parts	2.5	−1.8
Professional and scientific instruments	3.2	− .3
Miscellaneous manufacturing industries	2.7	4.2

REFERENCE: Appendix table 4-22.

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knitting and fabric-cutting equipment, so that output increased while labor inputs decreased.[125]

Primary metals is outstanding among the industries with lagging productivity performance. Declining productivity in the steel industry is technology-related. Primary metal imports have increased significantly in recent years. Because of stiff foreign competition, profits have been low, so that investment in more productive and technology-intensive new processes has been retarded. High expenditures on pollution control have had the same effect.[126] The printing and publishing industry also has many productivity-improving technologies available, but they are not yet fully diffused throughout the industry. The fabricated metal products industries construct many facilities such as bridges, broadcast towers, and building skeletons at customers' locations. Much of this is custom work for which assembly-line automation is impossible. The labor intensity and fragmented structure suggest low productivity growth.

Besides the problems of particular industries, the general decline in the rate of increase of nonfarm industrial productivity has been regarded as a national problem and has been attributed to some nationwide causes, many of which are technology-related. There has been a general decline in the growth of capital stock, and hence in the growth of the capital/labor ratio. This decline is attributed in part to higher levels of taxation, higher costs of borrowing money, and higher capital costs. Since technological innovations are often embodied in new capital equipment, this means that the effective rate of innovation has declined.[127] Government regulations are widely blamed for diverting industry resources from productive activities and from

[125]American Productivity Center, Houston, Texas, unpublished data, August, 1980; Nestor Terleckyj, private communication.

[126]Edward Meadows; American Productivity Center, Houston, Texas, unpublished data, August 1980.

[127]Scherer, p. 16, concludes that "the purchase or modification of capital equipment is the main vehicle through which the results of R&D lead to increases in measured productivity growth."

investment in high-technology equipment.[128] In addition, changes in energy prices are making some technologies obsolete. Current Administration policies of reducing corporate taxes and regulations are intended to alleviate these problems.[129]

Other possible explanations for weakened productivity performance are that the price of labor is increasing less rapidly than the price of other resources, so that more labor is being used per unit of output;[130] that the U.S. economy is losing its ability to deal with new circumstances, as conditions favoring entrepreneurship disappear;[131] and that advances in productivity and technology are being deterred by a new emphasis on short-term profitability at a time when high costs and risks are associated with long-term research and the construction of large, innovative production facilities.[132] Frequent turnover of management adds to this problem because such managers are likely to take a short-range view.[133]

Declines in industrial R&D are also alleged as reasons for declining productivity.[134] It is widely agreed that R&D has a significant, positive effect on productivity.[135] Thus, for a given level of total R&D expenditure, one study found that more long-term R&D in industry seems to lead directly and significantly to increased productivity.[136] Still, the relation of R&D expenditure to productivity improvement has been less clear in recent years.[137] There are several possible reasons: The character of R&D may have changed because of regulatory constraints and lack of investment incentives. Companies may have failed to take advantage of past R&D by not purchasing capital equipment embodying that R&D. The effective supply of funds available for capital investment is affected by Federal tax policy. The present method of taxing corporations allows depreciation deductions only on the basis of original equipment cost, not present inflated cost. Thus, the funds available for reinvestment are reduced. Uncertainty about future energy price changes and similar economic events may also have led to conservative company policies that failed to exploit new results of R&D.

In general, there has been a notable slowing in the rate of productivity improvement in U.S. industry since the mid-1960's. In many of the individual industries that show this slowdown, it can be attributed to a failure to adopt technological improvements. The technological know-how may

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[128] *Stimulating Technological Progress*, pp. 43-47. For a broad analysis of the steel industry, see *Technology and Steel Industry Competitiveness*, Office of Technology Assessment, 1980; Bela Gold, Gerhard Rosegger, and Myles G. Boylan, Jr., *Evaluating Technological Innovations* (Lexington, Mass.: D.C. Heath, 1980).

Others speak of shifts in the composition of the labor force, with the rapid entrance of inexperienced youths and women, as harming industrial productivity. Apparently this has not been a major factor since 1973 at least. See *Productivity: A Report Submitted to the Congress by the Council on Wage and Price Stability*, Council on Wage and Price Stability, July 23, 1979, p. 20. Also see "Productivity Problems Trouble Economy," *Science*, vol. 206 (October 19, 1979), pp. 310-311.

[129] *America's New Beginning: A Program for Economic Recovery*, Part III: *A White House Report*, Executive Office of the President, February 1981, pp. 4-9.

[130] Christopher T. Hill, "Technological Innovation: Agent of Growth and Change," in Christopher T. Hill and James M. Utterback, eds. *Technological Innovation for a Dynamic Economy* (New York: Pergamon Press, 1979), p. 13.

[131] Burton H. Klein, "The Slowdown in Productivity Advances: A Dynamic Explanation," in Christopher T. Hill and James M. Utterback, eds. *Technological Innovation for a Dynamic Economy* (New York: Pergamon Press, 1979), pp. 66-117.

[132] Bela Gold, p. 298.

[133] "Managers Who Are No Longer Entrepreneurs," *Business Week* (June 30, 1980), pp. 74-82; Robert H. Hayes and William J. Abernathy, "Managing Our Way to Economic Decline," *Harvard Business Review* (July/August 1980), pp. 67-77.

[134] The relation of R&D to productivity, and the problems of measurement, are summarized in Mary Ellen Mogee, *The Relation of Federal Support of Basic Research in Universities to Industrial Innovation and Productivity*, pp. 12-22. A discussion of recent findings is given in Eleanor Thomas, "Recent Research on R&D and Productivity Growth: A Changing Relationship between Input and Impact Indicators?", paper prepared for the Organisation for Economic Co-operation and Development Conference on Science and Technology Indicators, Paris, September 15-19, 1980.

[135] Edwin Mansfield, "Contribution of Research and Development to Economic Growth in the United States," in *Research and Development and Economic Growth/Productivity*, National Science Foundation (NSF 72-303), 1972; Edwin Mansfield, "Research and Development, Productivity Change, and Public Policy," in *Preliminary Papers for a Colloquium on the Relationship between R&D and Economic Growth/Productivity*, National Science Foundation, November 9, 1977; Robert E. Evenson, Paul E. Waggoner, and Vernon W. Ruthan, "Economic Benefits from Research: An Example from Agriculture," *Science*, (Sept. 19, 1979), pp. 1101-1107; Nestor E. Terleckyj, "What Do R&D Numbers Tell Us about Technological Change?", paper given at the Annual Meeting of the American Economic Association, Atlanta, December 28, 1979.

A research project in progress has found very high productivity improvements in the domestic air transport industry due to R&D investments in the domestic aircraft industry. Returns from R&D investment are at least an order of magnitude greater than returns from alternative investments. See Ralph C. Lenz, John A. Machnic, and Anthony W. Elkins, *The Influence of Aeronautical R&D Expenditures upon the Productivity of Air Transportation* (Dayton, Ohio: University of Dayton Research Institute, July 1981). On the relation between tax policy and productivity or economic growth in general, see *Preliminary Papers for a Colloquium on Tax Policy and Investment in Innovation*, National Science Foundation, 1981.

[136] Edwin Mansfield, quoted in "Productivity Problems Trouble Economy," *Science*, vol. 26 (October 19, 1979), p. 311; Edwin Mansfield, "Basic Research and Productivity Increase in Manufacturing," *American Economic Review*, vol. 70 (December 1980), pp. 863-873; Terleckyj. Methodological problems are discussed in Griliches; Gold, pp. 27-30; and Klein, p. 71.

[137] Griliches, pp. 92-116; Scherer, pp. 9-16.

be available, but for several reasons some companies are not investing in the new capital equipment that would put that know-how into operation. Influences not directly related to technology are also adversely affecting productivity. R&D is generally agreed to have a positive long-range effect on productivity, but its role in the recent productivity trends is less clear.

Summary—Outputs Section

In the present state of development of output indicators, only a few tentative conclusions can be drawn about the overall state of industrial technology in the United States. A decline in the rate of patenting by Americans has been taking place since 1971 in almost all product fields. Behavior limited to a few fields, such as an increasing tendency not to patent new inventions in certain technologies, cannot account for this widespread phenomenon. Thus, there is evidence that the rate of production of technical inventions has been declining.

Trends in industrial labor productivity give a similar picture. The rate of productivity improvement since 1965 has been lower than the rate from 1957 to 1965, for both manufacturing and nonmanufacturing industries. Reasons for the weakening in productivity improvement in some industries include diversion of R&D and capital funds into pollution control and other regulatory requirements. Slow growth of capital stock is also attributed to price increases and management conservatism. The result is that new technology embodied in capital equipment, which could improve productivity, fails to diffuse throughout a particular industry.

Patenting represents a stage in the process of technological innovation prior to the commercial introduction of a technology. Productivity represents a much later stage, in which the effects of technological improvement combine with the effects of various economic conditions. Even in the case of productivity, R&D is generally believed to have a positive influence. The declines in patenting and in constant-dollar R&D funding, coupled with the productivity declines, suggest that since the early 1970's U.S. industrial technology has not been improving at the pace of earlier years.

Some conclusions can also be drawn about specific technologies and industries. A case study based on composite technical performance indices shows that computer technology had its greatest improvements in the 1950's and 1960's with the introduction of magnetic core memories, transistors, and integrated circuits. In antibiotics, the greatest single development has been the introduction of penicillin in the 1940's. Cumulative progress since that time has been about equal to that one advance alone.

In terms of productivity, the petroleum industry has done especially well since 1957, in part because of increased automation. Patenting in this industry has also increased dramatically in the last few years, evidently a result of the accelerated search for domestic oil and gas supplies. Most patenting in energy-related technologies is in fossil fuels and electric power, but the greatest increase from 1973 to 1978 was in solar energy, as both industry and independent individuals sought to exploit this domestically available and nonpolluting energy source. The industry that seems to be having the most difficulties, in productivity terms, is primary metals. Productivity in that industry actually declined by 3 percent per year from 1973 to 1978, with a further decrease estimated for 1979. Patenting in primary metals also decreased significantly from 1976 to 1978. Much of the productivity drop is attributed to low levels of investment in more productive and technically advanced capital equipment. This low rate of investment, in turn, is attributed to low profits because of foreign inroads into the market, and also to the diversion of corporate capital into pollution abatement and other regulatory requirements.

Chapter 5
Scientific and Engineering Personnel

Scientific and Engineering Personnel

INDICATOR HIGHLIGHTS

- Employment in science and engineering (S/E) jobs remained relatively constant at 2.1 million between 1976 and 1978. Over this period, the number employed in engineering jobs increased by about 7 percent, while the number in science occupations declined by 8 percent. With the exception of computer specialists and environmental scientists, employment in S/E jobs fell for all major fields of science. The strong growth in the employment of engineers, computer specialists, and environmental scientists continued throughout 1980. (See p. 129.)
- Available labor market indicators show consistent patterns of shortages for engineers and computer specialists and ample supplies of social and life scientists. The market for physical scientists has been improving, and supply and demand were relatively balanced in mid-1980. (See pp. 140-144.)
- In recent years, employment in science and engineering has grown more slowly (2.5 percent per year) than total U.S. employment and GNP (4 percent per year), indicating shifts in national activity patterns away from those related to science and technology. (See p. 129.)
- In 1978, the S/E utilization rate (those in S/E jobs as a percent of all scientists and engineers employed or looking for jobs) was 83 percent, down slightly from 1976. The decline in the utilization rate was accounted for entirely by scientists. Rates fell for mathematical, life, and social scientists (including psychologists), and increased for physical and environmental scientists and computer specialists. (See pp. 141-142.)
- Most employed S/E's work in science and engineering jobs, with the proportion varying from almost 100 percent of the computer specialists to about one-half of the social scientists. The majority of those working outside science and engineering are doing so on a voluntary basis. (See p. 128.)
- Only about one-half of employed recent bachelor's degree graduates and three-fourths of the master's degree graduates in science and engineering were working in science or engineering jobs. Among the major fields, the proportions of recent graduates in science and engineering jobs were consistently higher for engineering graduates and lower for social science graduates. Of those working in non-S/E jobs, 26 percent at the bachelor's level and 14 percent at the master's level were doing so involuntarily. The remainder were in non-S/E jobs because of personal preference, better pay, etc. (See pp. 150-151.)
- The doctoral "intensity" of the industrial S/E work force has increased over time because business and industry has been one of the fastest growing employment sectors for doctoral level S/E's. In the early 1970's, about 10 percent of the employed S/E's in industry held doctorates; by the late 1970's, the proportion rose to slightly over 13 percent. Thus, employers are enriching their staffs by taking advantage of the greater availability of S/E doctorates. (See p. 135.)
- There are concerns about declining employment opportunities for young doctorate holders in academia and the possible implications of these declines on research vitality. The proportion of doctoral S/E's under 35 years of age in educational institutions declined by 30 percent. This decline might have been greater except that the number holding postdoctoral appointments (who are generally under 35 years of age) almost doubled. (See pp. 138-139.)
- There have been increasing concerns about the quality of the science and engineering work force. Though limited, indicators show that the quality of the S/E work force has not declined. For example, the proportion of doctorate-holding S/E's has increased, and test scores of prospective graduate students remain high. (See pp. 130-131.)
- Women are still underrepresented in S/E jobs despite rapid employment growth in recent years. Between 1976 and 1978, employment of women scientists and engineers increased by 17 percent versus 3 percent for men. Women represent about 9 percent of all employed S/E's and account for over 40 percent of all employed professional and technical workers. (See p. 144.)

- Members of racial minority groups are under-represented in S/E jobs even though their employment has been increasing at a faster rate than employment of white S/E's. For example, between 1974 and 1978, employment of blacks increased by 20 percent, while the increase among white scientists and engineers was about 10 percent. Only about 4.5 percent of employed S/E's are members of racial minority groups, compared to about 9 percent of all professional and technical workers. (See pp. 144-145.)

This chapter presents an overview of the Nation's scientists and engineers (S/E's), followed by an examination of the school-to-work transition of recent science and engineering graduates. The overview begins with an assessment of current and projected S/E utilization and supply and focuses on trends in employment and labor market conditions. The roles and progress of women and racial minorities in science and engineering are examined as part of the general topic of S/E labor markets.

Until recently, little information was available to assess trends in job opportunities for the large numbers of people earning bachelor's and master's degrees in science and engineering. The final section of this chapter looks at the school-to-work transition of recent S/E graduates. Employment trends of recent graduates provide a sensitive barometer of overall labor market conditions in the various science and engineering fields since changes in employer demands generally are reflected first in employer hiring decisions. New indicators help assess the degree of possible underutilization and underemployment of recent graduates. Where appropriate, indicators are described that help monitor the progress of recent graduates who are women or members of racial minority groups.

The interpretation of the statistical indicators used in this chapter has limitations. For example, causal relationships cannot be inferred only from observed statistical associations. To illustrate, it cannot be assumed that a disparity between men and women in the propensity to find S/E-related jobs is necessarily due to sex discrimination. Also, while wages are influenced by the interaction of market forces (i.e., personnel requirements on the one hand and the available supply of personnel on the other), wages, in turn, influence both the magnitude of the supply and the extent of personnel utilization. These limitations suggest that care should be exercised in drawing conclusions from single indicators. Generally, further analysis involving other indicators is required. This is done in the report, and the data presented illuminate the current status of scientists and engineers and suggest future changes.

Differences in concepts, data collection techniques, and statistical reporting procedures exist for some of the statistics. Readers wishing to understand the indicators and their limitations more fully are urged to consult the primary data sources listed in the appropriate references and appendix tables.

TRENDS IN SCIENCE AND ENGINEERING EMPLOYMENT

Scientists and engineers play important and pervasive roles in almost every aspect of modern life, and changes in science and engineering employment can indicate changes in the nature, direction, and level of the U.S. science and technology enterprise.

Several indicators can be used to assess trends in science and engineering employment, but first it is useful to distinguish between the employment of those who are scientists and engineers (S/E's) by virtue of their education and experience and the employment of those S/E's in science and engineering jobs. Trends in the number employed in science and engineering reflect more directly the human resources involved in carrying out U.S. science and technology efforts.

The following indicators focus on changes in S/E employment compared to changes in overall national employment and economic activity, the work activities of S/E's, and the quality of the science and engineering work force. Recently, employment in science and engineering has grown more slowly than total U.S. employment and overall economic activity, implying shifts in national activity patterns (as measured by market responses) away from those related to science and technology. A shift from science toward engineering was evidenced by increases in engineering employment and decreases in the employment of scientists. Among scientists, only computer specialists and environmental scientists showed employment increases. With respect to work activities, there was a slight shift toward research, rather than development, and away from teaching. Finally, the quality

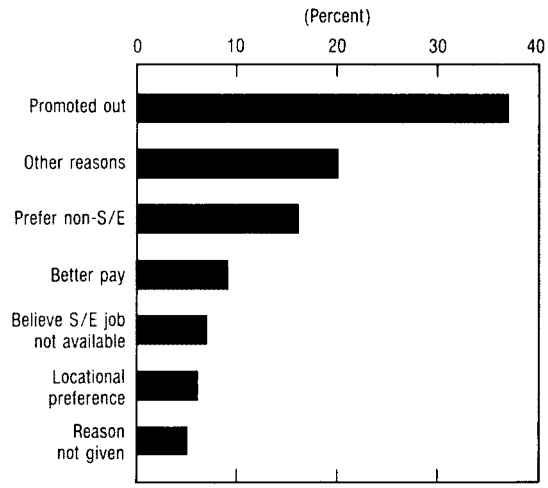
of the U.S. science and engineering work force remains high and, as measured by educational attainment, continues to improve.

Non-S/E Employment

For many reasons, some S/E's hold jobs outside science and engineering altogether. Of the S/E's employed in 1978, about 85 percent (2.1 million) reported they were in science and engineering jobs, down from 88 percent in 1976. By field, the proportion in S/E jobs ranged from about 99 percent of the computer specialists to approximately 50 percent of the social and mathematical scientists (see figure 5-1).

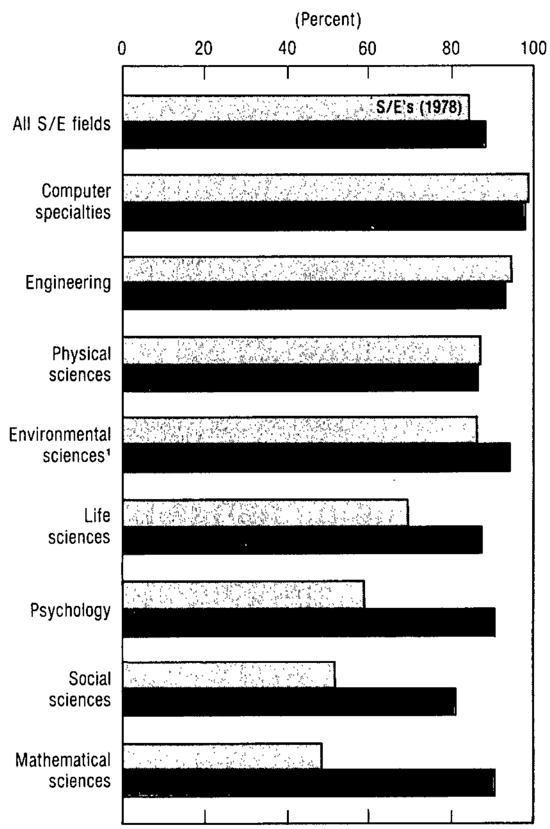
The fact that some S/E's are employed in non-S/E jobs does not necessarily mean that they are being underutilized from a societal perspective. Their technical training can provide insight that can be quite valuable to their nontechnical activities. Some S/E's choose to work in non-S/E jobs for higher pay or other personal reasons. Others work outside of science and engineering because they believe S/E jobs are not available. Of those experienced S/E's who were in the labor force in 1970 and held non-S/E jobs in 1978, only about 7 percent reported this to be the case, while almost two-thirds reported they were in non-S/E jobs because of personal preference, promotions, or higher pay (see figure 5-2). The proportion of the experienced S/E's "involuntarily" employed outside science and engineering varies somewhat by field (see appendix table 5-6). However, the majority are outside of science and engineering on a voluntary basis. This same phenomenon is observed among those earning S/E bachelor's and master's degrees in 1977, with about 75 to 85 percent, respectively, working outside of S/E in 1979 for voluntary reasons (see appendix table 5-7).

Figure 5-2
Reasons for non-science and engineering employment of experienced scientists and engineers: 1978



REFERENCE: Appendix table 5-6. Science Indicators—1980

Figure 5-1
Percent of employed S/E's in science and engineering jobs



[1]Includes earth sciences, oceanography and atmospheric sciences.
REFERENCES: Appendix tables 5-2 and 5-5. Science Indicators—1980

Employment in Science and Engineering

A broad measure of the level of scientific and technological activity in the United States is the number of individuals employed as scientists and engineers (ES/E's).[1] Comparisons of ES/E's employment trends to other employment trends and to

[1]ES/E symbolizes those scientists and engineers employed in science and engineering.

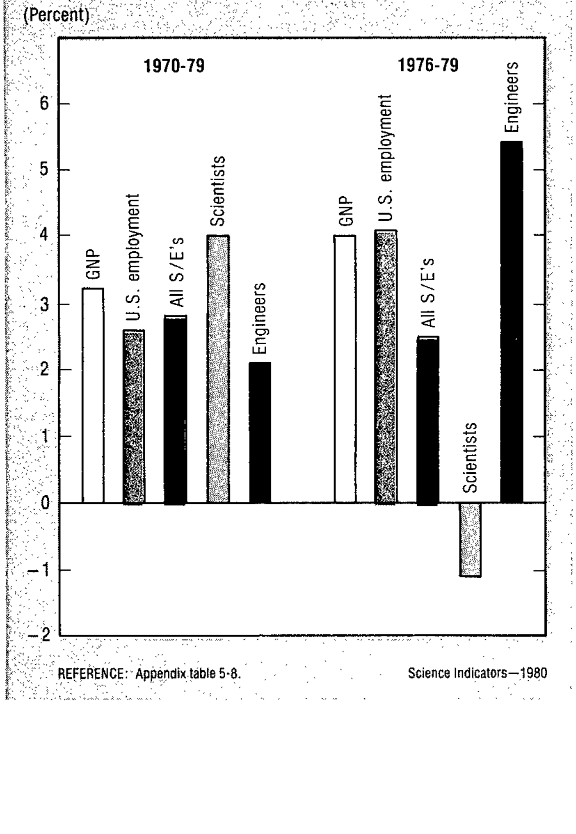
changes in indicators of economic activity are useful since they illuminate shifts in de facto national priorities. If ES/E employment increases less rapidly than total employment or other economic indicators, the comparison suggests that society may be giving higher priority to nontechnical activities at the expense of technical ones. Another explanation to be explored is whether or not the productivity of the scientific and engineering work force is increasing. Indicators of the productivity of the ES/E work force, however, remain to be developed.

Between 1970 and 1979, employment of ES/E's grew at a slightly faster rate than total employment, but at a slower rate than overall economic activity.[2] Between 1970 and 1979, ES/E employment grew at an average annual rate of 2.8 percent (4.0 percent for scientists and 2.1 percent for engineers). Real gross national product—an indicator of overall economic activity—increased at an average annual rate of 3.2 percent, while total U.S. employment increased by 2.6 percent per year (see figure 5-3). This more rapid growth in scientific fields was strongly influenced by growth in the employment of computer specialists and social scientists (including psychologists).

Between 1976 and 1979, employment in science and engineering grew more slowly than did total employment or the Gross National Product (GNP). However, employment of engineers increased 5.4 percent per year, while employment of scientists declined 1.1 percent per year. With the exception of computer specialists and environmental scientists, employment fell in all scientific fields. By 1979, the number of individuals employed as scientists and engineers climbed to almost 2.3 million, about 8 percent above 1976 levels. The employment increases for engineers, computer specialists, and environmental scientists reflect an increased demand for these personnel in private industry.

[2]Estimates of the number employed in science and engineering (ES/E's) for 1979 are preliminary estimates developed by the National Science Foundation. NSF survey data are not available after 1978. In addition, data on employment of scientists and engineers in science and engineering prior to 1976 were estimated by NSF for engineers and for all scientists combined. Data on the number employed in science and engineering classified by variables, such as sector of employment and primary work activity, are not available prior to 1978.

Figure 5-3
Average annual growth in ES/E employment and other manpower and economic variables



REFERENCE: Appendix table 5-8. Science Indicators—1980

Character of S&T Activities

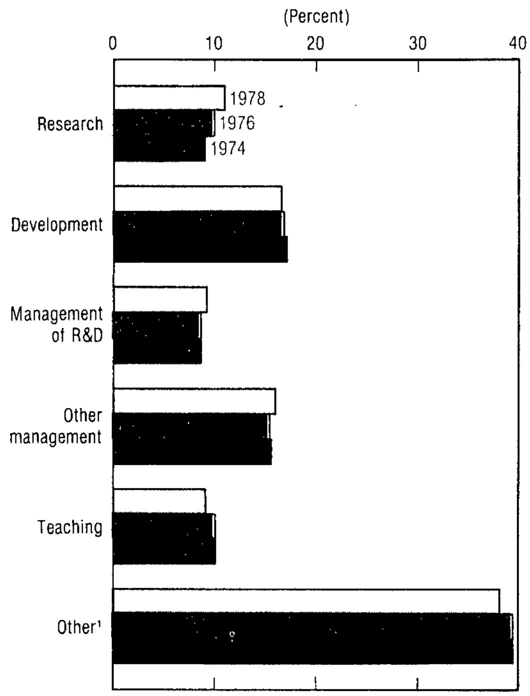
Another and perhaps more direct indicator of the nature or character of U.S. science and technology is the distribution of work activities of scientific and technical personnel.[3] Changes in the number engaged in these activities reflect significant shifts in the character of U.S. S&T efforts. Furthermore, the number of R&D personnel is a leading indicator of the Nation's overall science and technology effort which depends heavily on innovation which, in turn, is largely based on R&D.

In 1978, about 37 percent of the employed S/E's reported their primary work activity as R&D or R&D management (see figure 5-4). The next most common activity was management other than R&D (16 percent), followed by teaching (9 percent). The distribution of work activities has changed only slightly since the mid-1970's. However, small changes in the patterns of primary work activities can mask sizeable shifts in absolute employment changes (see appendix table 5-9).

The number of S/E's primarily employed in R&D (excluding R&D management) increased by 9 percent (57,200) to 685,300 between 1976 and 1978. The number in research increased at a substantially faster rate (20 percent) between 1976 and 1978 than did the number in development (2.7 percent). Over 80 percent of the increase in R&D employment was accounted for by those primarily engaged in research. Employment in both basic and

[3]All employed scientists and engineers, not just those in science and engineering jobs.

Figure 5-4
Scientists and engineers by primary work activity



[1]Includes consulting; production/inspection; reporting, statistical work and computing, and those who did not report their primary work activity

REFERENCE: Appendix table 5-9. Science Indicators—1980

applied research grew at roughly similar rates between 1976 and 1978. These data show a recent shift away from development activities and towards research activities. The increased emphasis on research rather than development, in part, reflects funding priorities. The focus of Federal R&D obligations changed significantly over the 1970's, with an increase in research relative to development.[4]

Most of the increase in the number of S/E's primarily employed in R&D took place among scientists rather than among engineers. The number of scientists reporting research as their primary work activity jumped 25 percent between 1976 and 1978, from 182,000 to about 228,000. In development activities, the number of scientists increased by about 16 percent, or by 11,000, over the 2-year period. Among engineers, the number primarily employed in R&D activities (excluding R&D management) remained essentially constant during the same period.

Growth in the employment of engineers was concentrated among those reporting their primary work activity in production-related activities. Since engineers are concentrated in industry, the increase in production-related activities implies that industry may be placing greater emphasis on measures to increase production and improve quality control procedures.

Quality of the S/E Work Force

Generally, heightened concern about the quality of the scientific and technical work force[5] has replaced earlier concerns relating to quantity. No direct measure of overall workforce quality exists. However, several indirect indicators may be used, such as test scores of prospective graduate students and the proportion of the S/E work force holding doctorates. Though limited, these data indicate that the quality of the S/E work force has not declined. The proportion of S/E's holding the doctorate has increased, and test scores of prospective graduate students remain high.

Test Scores of Prospective Graduate Students. From 1970 to 1978, the quality of prospective S/E graduate students, as measured by test scores on the verbal and quantitative components of the Graduate Record Examination (GRE), remained high in absolute terms and relative to the average scores of graduate students in nonscience fields (see appendix table 5-12).

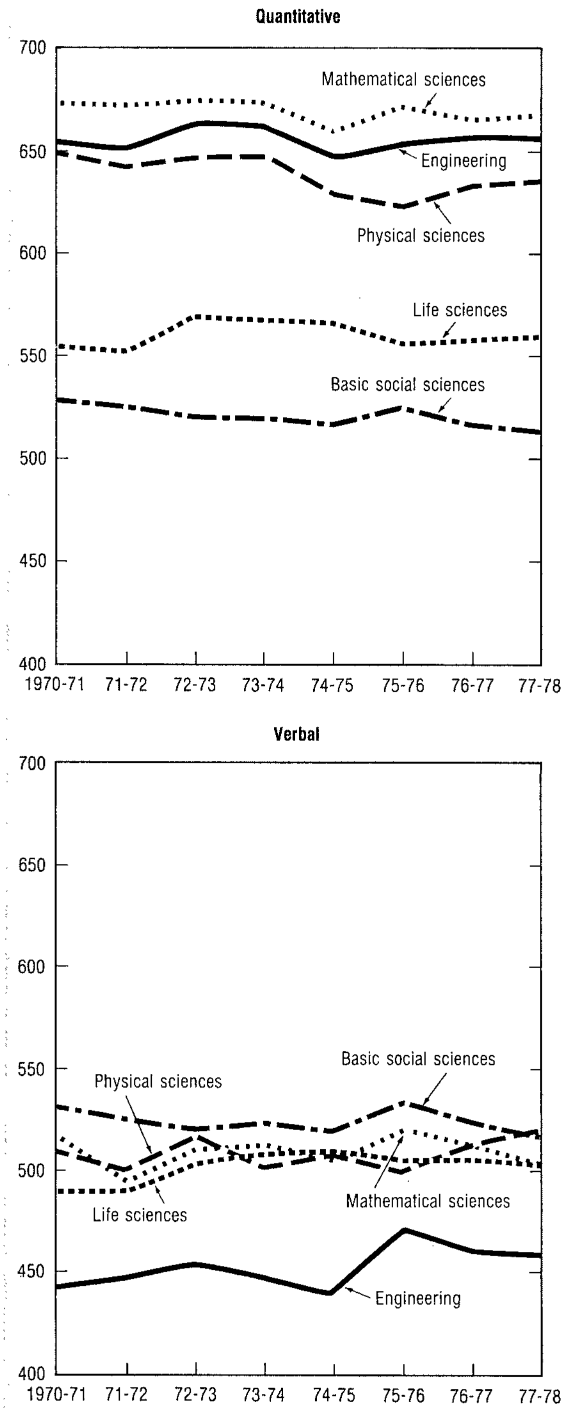
Mean scores are available for 1970 to 1978 for five broad S/E fields (figure 5-5). In verbal ability, scores for science and nonscience candidates did not differ significantly, but engineering candidates' scores averaged noticeably lower than scores of science candidates. The lower verbal scores for engineering candidates may be influenced by the relatively large numbers of foreign students entering graduate engineering programs. In quantitative ability, candidates for admission to S/E fields scored significantly higher than candidates in nonscience fields, but there were large differences separating candidates in engineering, mathematics, and physics from those in the life and social sciences.

Not only has the quality of prospective graduate students remained fairly constant, but the proportion of doctorates granted by top-rated departments for selected fields has been relatively stable from 1967 to 1977. Although the number of doctorates granted in S/E has declined since the early 1970's, the downward trend in the number of doctorates

[4]*National Patterns of Science and Technology, 1980*, National Science Foundation, (NSF 80-308), pp. 5, 30-32.

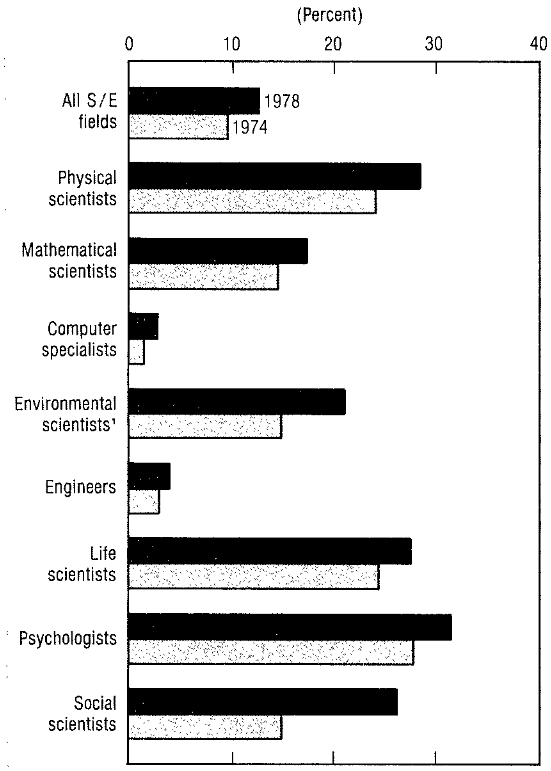
[5]See, for example, *Science and Engineering Education and National Needs: An Overview*, prepared by the U.S. Department of Education and the National Science Foundation, 1980, unpublished.

Figure 5-5
Mean scores on graduate record examination verbal and quantitative aptitude tests by prospective field of graduate study



REFERENCE: Appendix table 5-12. Science Indicators—1980

Figure 5-6
Doctoral S/E's as a percent of all employed S/E's



¹Includes earth scientists, oceanographers and atmospheric scientists.
NOTE: Data are only available for doctoral S/E's for 1973, 1975, 1977 and 1979 and for all S/E's for 1974, 1976 and 1978. Therefore, percents were calculated by dividing 1973 doctoral S/E's by 1974 S/E's and by dividing 1979 doctoral S/E's by 1978 S/E's to obtain these 1974 and 1978 data, respectively.
REFERENCES: Appendix tables 5-2 and 5-3. Science Indicators—1980

awarded by those with a distinguished "Roose-Anderson" rating has proceeded at a slower rate than the trend in lesser rated departments.[6]

Doctoral Scientists and Engineers. Since doctoral level S/E's provide much of the leadership in scientific activities, it is useful to measure the relative growth in this component of the employed work force. S/E's with doctorates are becoming an increasingly important part of the S/E work force. In 1974, about 10 percent of the employed S/E's held doctorates. By 1978, the proportion had risen to about 13 percent, with substantial field variation. While the proportion of S/E's holding doctorates increased in all fields, significantly large increases were noted among social scientists (see figure 5-6).

[6] *Summary Report 1977: Doctorate Recipients from United States Universities* (Washington, D.C.: National Academy of Sciences, 1978).

SECTORAL EMPLOYMENT

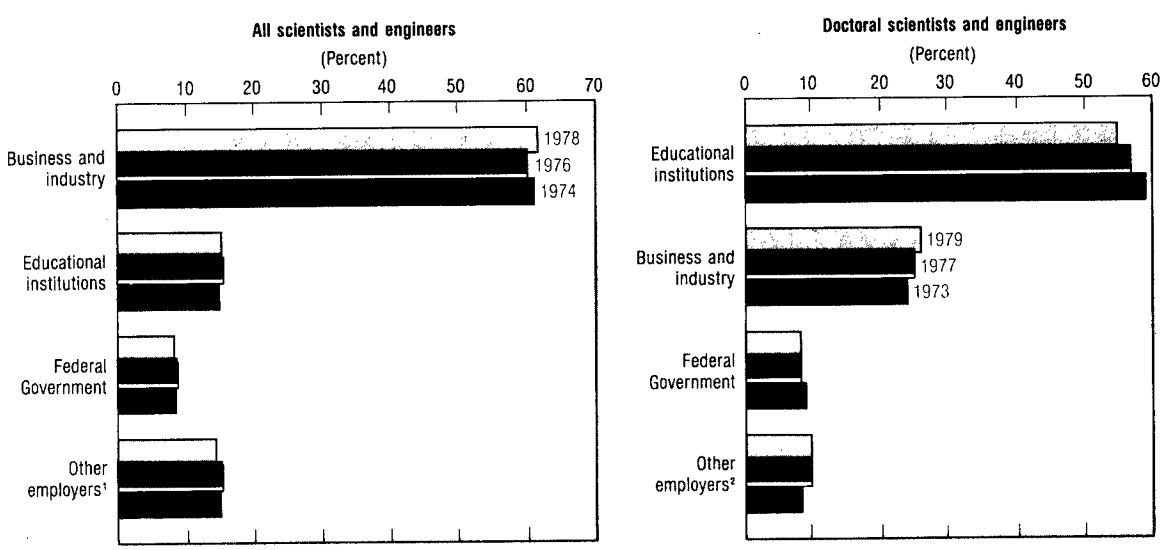
The nature of science and technology activities in different economic sectors varies considerably. Development activities are primarily carried out in the industrial sector of the U.S. economy. Basic research and teaching, on the other hand, are concentrated in universities and colleges. Each sector has unique capabilities that permit it to achieve its objectives. Thus, changes in the sectoral employment of S/E's are another indicator of changes in the character of the S&T enterprise that reflect the myriad decisions that drive U.S. science and technology.

Most S/E's (62 percent or 1.5 million) work in the private business and industry sector (see figure 5-7). Educational institutions rank a distant second. The sectoral distribution of employed S/E's has remained relatively constant over the 1970's, although a slight shift towards industry is evident in the latter part of the decade. At the doctoral level, most S/E's (55 percent) are employed in educational institutions, with only about one-quarter (26 percent) in business and industry. Since 1973, however, there has been a shift in employment of doctoral S/E's from educational institutions toward business and industry.

Both industry and academia face unique problems with respect to scientific and technical personnel, in part because of differential growth rates in employment and differences in the nature of their respective activities. Tenure and job opportunities are the principal issues in the academic sector. Shortages in specific occupations and the inability to recruit the desired numbers of women and racial minorities in science and engineering are problems in the business and industry sector. The industrial sector warrants special attention since most S/E's are employed in industry and most R&D activities are undertaken by industry. Additionally, technology generated by industry is a principal means by which the results of scientific research are translated into applications. The academic sector warrants attention because a large fraction of our scientific knowledge is developed through basic research in academic institutions, and universities and colleges train future scientists and engineers.

Indicators used to examine the role of S/E in business and industry, and the nature of the science and technology efforts in industry—concentration ratios, work activities, and doctoral "intensity"—reveal several findings: (1) technical activities have been growing at a slower rate than nontechnical activities; (2) almost all engineers but only 80 percent of the scientists are engaged in science and engineering work; and (3) of those in science and engineering work, the number in de-

Figure 5-7
Distribution of scientists and engineers by sector of employment



[1]Includes nonprofit organizations; military; state/local/other government; other and no report.
[2]Includes nonprofit organizations; hospitals/clinics; and those who did not report their sector of employment.
REFERENCES: Appendix tables 5-13 and 5-14.

Science Indicators—1980

velopment activities is more than three times the number engaged in research activities. However, over half of both the scientists and of the engineers in industry are in activities other than R&D or its management. Finally, the doctoral "intensity" of industrially employed S/E's has been increasing over the 1970's.

Indicators used to examine the college and university sector show that employment increases among S/E's have recently slowed considerably and that the field distribution of S/E's has changed over the 1970's. Employment of physical, mathematical, and environmental scientists has increased at below average rates, while employment of social scientists and computer specialists increased at above average rates. The work activities of S/E's in academia are also changing. Among those holding the Ph. D., the number reporting R&D as their primary activity increased much more rapidly than those reporting teaching as their primary activity. Academic concerns about the implications of declining permanent employment opportunities on research vitality are illuminated by indicators showing that the proportion of Ph. D.'s under 35 years of age at colleges and universities has declined, the number on postdoctoral appointments has doubled, and tenure approval rates are about equal to overall tenure rates among full-time S/E faculties. The indicators show some loss of young scholars to academia, and some observers believe this loss may be an impediment to research progress.

Overall, S/E employment in business and industry increased by 7 percent between 1976 and 1978 and remained virtually unchanged in all other sectors combined. Among doctoral scientists and engineers, employment in business and industry increased more rapidly than in other sectors. Between 1973 and 1979, employment of doctoral S/E's in industry increased by 55 percent, while in educational institutions the increase was about 34 percent.

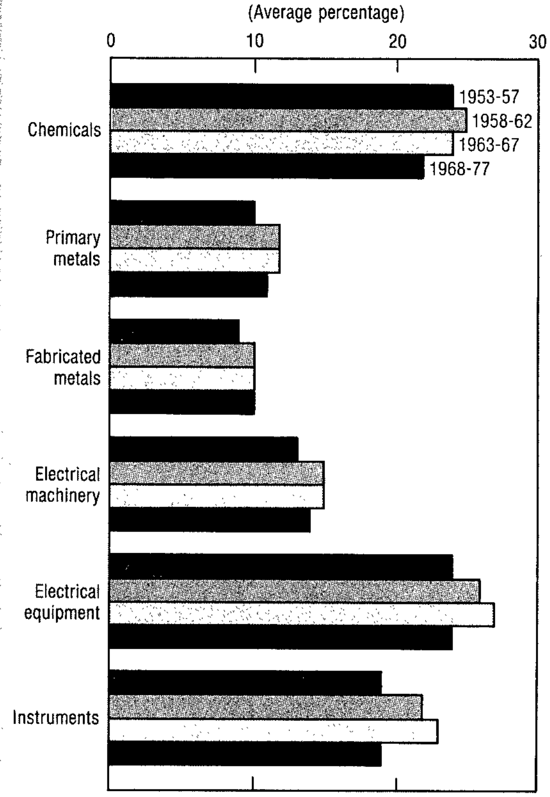
The relatively rapid growth in industry results from several factors, such as the expansion in overall activity that accompanied the recovery from the 1974-75 recession and, for doctorates, the hiring of young S/E's for R&D activities. The relatively slower growth in employment in educational institutions reflects the tapering off of enrollment growth due, in part, to demographic factors. Demographic trends indicate that slower enrollment growth (and possible declines) can be expected through the mid-1980's.

Business and Industry

Business and industry is the largest employer of both scientists (45 percent) and engineers (78 percent). Additionally, (based on expenditures) industry performs 85 percent of all development activities, 60 percent of applied research activities, and 16 percent of basic research activities.[7]

Figure 5-8

Employed S/E's as a proportion of total nonproduction workers in selected industries



NOTE: Excludes social scientists and psychologists.
REFERENCE: Appendix table 5-15.
Science Indicators—1980

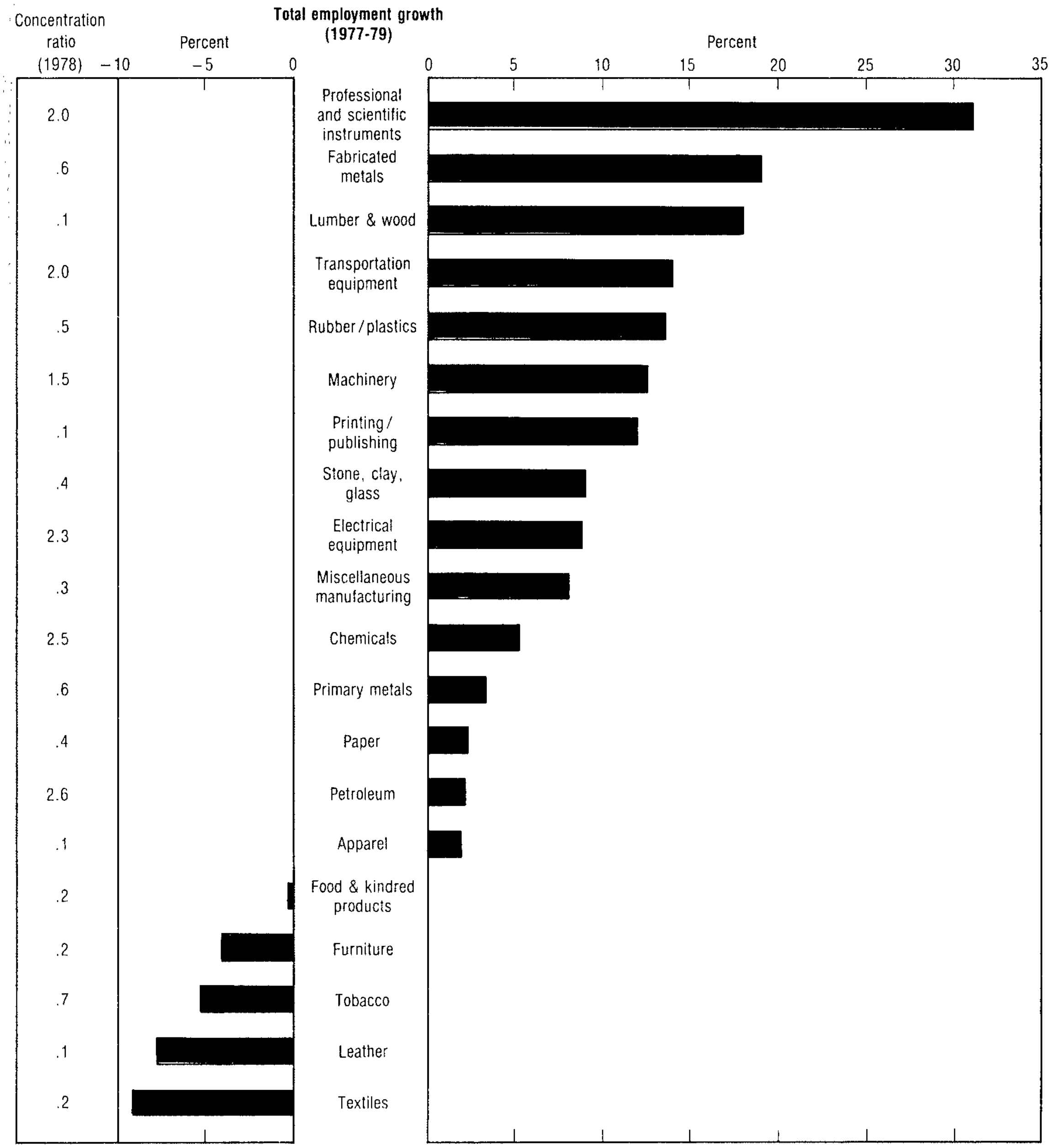
Available evidence suggests that, since 1967, nontechnical activities[8] have been growing at a faster rate than technical activities in some manufacturing industries that are major employers of scientists and engineers. This conclusion is based on comparisons between employment of S/E's[9] and total employment of persons not directly engaged in production work, for which consistent estimates are available over time (see figure 5-8). The

[7] *National Patterns of Science and Technology*, 1980, pp. 26-28.

[8] Nontechnical activities include general management, accounting, clerical, and similar functions.

[9] Excluding social scientists and psychologists, for whom data are not available.

Figure 5-9
Concentration ratios[1] and employment growth



[1]A concentration ratio relates each industry's share of science and engineering employment to its share of total (i.e., S/E plus non-S/E) employment. That is: $C_i = (S_i/S) / (E_i/E)$, where C_i is the concentration ratio for industry i, S_i is the number of scientists and engineers in industry i, S is the total number of scientists and engineers in the sector (manufacturing), E_i is the total employment in industry i, and E is the total employment in the sector.

REFERENCE: Appendix table 5-17.

Science Indicators—1980

number of employed S/E's, while generally increasing, is not growing as rapidly as other support staff.

Manufacturing industries whose relative concentration of S/E's is "high" have grown at a significantly faster rate, as measured by changes in total employment, than industries with "low" concen-

trations (see figure 5-9). Within the nonmanufacturing sector,[10] there appears to be little if any relationship between concentrations of S/E's and growth in total employment.[11]

The concentration ratio for each industry relates that industry's share of science and engineering employment to its share of total (i.e., S/E and non-S/E) employment. A ratio close to unity (1.0) implies that S/E employment is primarily the result of the level of economic activity reflected by total employment. A ratio greater than unity implies relatively intensive use of S/E skills. The concentration ratio is a means of decomposing two effects on the employment of S/E's in an industry: the scale effect resulting from the level of production, and the effect of differing technology in producing each industry's output.

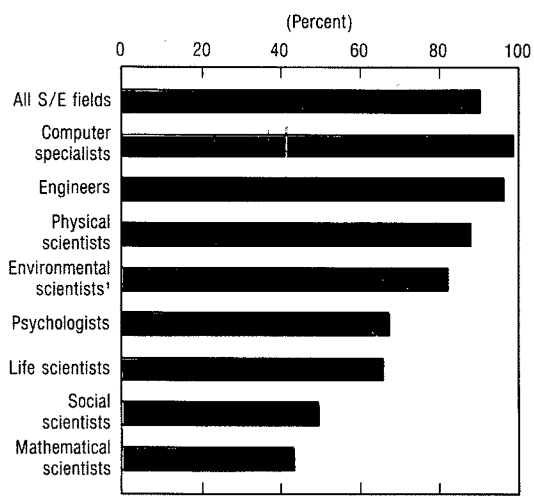
Based on concentration ratios, the petroleum refining industry utilizes almost 2.6 times as many S/E's as would be expected on the basis of total employment. Other industries with high S/E concentrations in the manufacturing sector include chemicals, electrical equipment, scientific instruments, and machinery (see appendix tables 5-16 and 5-17).

[10]The nonmanufacturing industries within the private sector include mining, construction, finance, insurance, real estate, and services such as engineering and architectural services and commercial R&D organizations.

[11]Based on unpublished NSF analysis, the coefficient of correlation between concentrations of S/E's and total employment growth in nonmanufacturing is not statistically significant (r = -.02).

Figure 5-10

Proportion of industrially employed S/E's in S/E jobs by field: 1978



[1]Includes earth scientists, oceanographers and atmospheric scientists.
REFERENCES: Appendix tables 5-13 and 5-18.

Science Indicators—1980

Work Activities. Of the over 1.5 million S/E's—985,000 engineers and almost 543,000 scientists—who were employed in business and industry, about 90 percent held scientific and engineering jobs. Almost all (97 percent) of the engineers employed in industry in 1978 reported they were working in S/E jobs, as did 79 percent of the scientists. Among scientists, the proportion varied considerably by field (see figure 5-10).

Of those in S/E jobs, about one-third reported R&D as their primary work activity with an additional 11 percent reporting R&D management as their primary work. Within R&D, the number engaged in development activities (347,000) was much greater than for basic (25,000) or applied (79,000) research. Other management activities; production and inspection; and reporting, statistical, and computation work were also cited by significant numbers of individuals as their primary work activities (see appendix table 5-20 and figure 5-11).

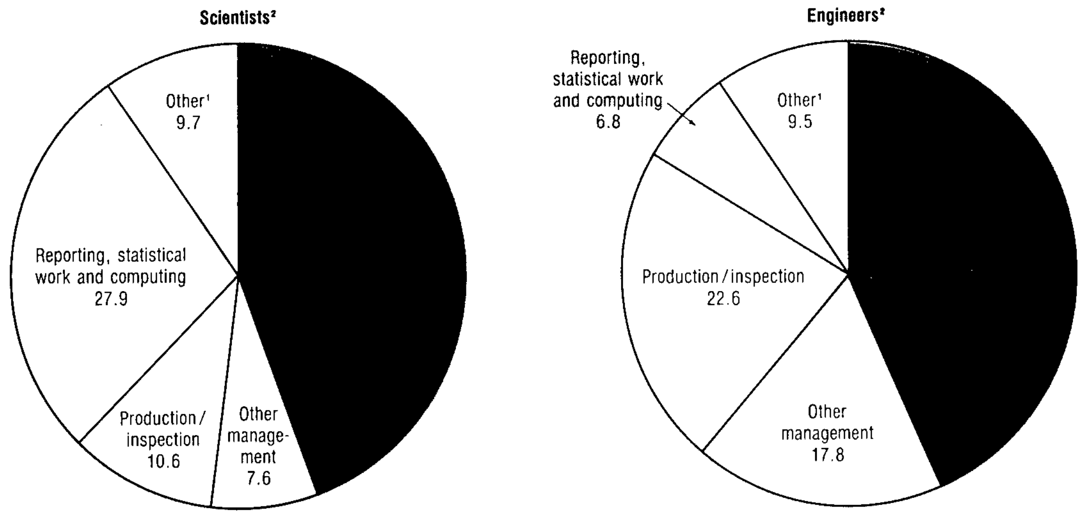
Doctoral S/E's in Industry. Business and industry has been one of the fastest growing sectors of doctoral S/E employment, up 16 percent between 1977 and 1979 and 55 percent since 1973. As a result of this growth, the Ph. D. "intensity" of the industrially S/E work force has been increasing over time. From the early to late 1970's, the ratio of industrially employed S/E doctorates to total S/E's has increased from about 1 in 25 to about 1 in 18. This increase may be due to the greater availability of S/E doctorates and/or requirements for a more highly trained technical work force. While most industrially employed S/E doctorates were primarily engaged in R&D and its management, the proportion declined from 71 percent in 1973 to 66 percent in 1979.

Areas of Concern. Management personnel in a number of firms that employ large numbers of S/E's were contacted in the early summer of 1980 to determine if they faced any significant issues concerning S/E personnel. Employers reported that the demand for computer specialists and engineers continued to be greater than the available supply, although the supply/demand situation was closer to balance than in the summer of 1979. At the entry level, employers cannot recruit the numbers of women and racial minorities in science and engineering they would like to employ. It was noted, however, that the supply of women has been increasing and that the supply and demand situation was loosening from very tight levels. Minority science and engineering entrants, however, remain in short supply.

Other areas investigated included obsolescence

Figure 5-11
Scientists and engineers (es/e) in business and industry by primary work activity: 1978

(In percent)



¹Includes teaching, consulting, other activities, and those who did not report their primary work activity
²These distributions are based on 430,800 scientists and 951,700 engineers.
REFERENCE: Appendix table 5-20.

Science Indicators—1980

of skills and the recent changes in the mandatory retirement laws. Skill obsolescence was not reported to be a problem since firms sponsor training programs and a sufficient number of S/E's are given the opportunity to participate in both on-the-job and other training programs. Employers indicated that very few S/E's are postponing retirement because of changes in mandatory retirement legislation. Thus, they do not expect the effects of this legislation to alleviate their recruiting problems by reducing the number of hires required to replace those who leave.

Universities and Colleges

In 1978, educational institutions employed approximately 381,000 S/E's, with scientists greatly outnumbering engineers (see appendix table 5-13). Educational institutions employ about 28 percent of all scientists and about 4 percent of all engineers. Between 1974 and 1978, employment of S/E's in educational institutions increased by 12 percent. This growth, however, was not uniform over the period. The 1976-78 S/E employment growth rate (2.7 percent) was about one-third the rate experienced between 1974 and 1976 (8.6 percent). Data from surveys of institutions of higher education show that the slower growth over the 1976-78 period was concentrated among institutions that do not offer degrees in science or engineering, primarily 2-year colleges.[12]

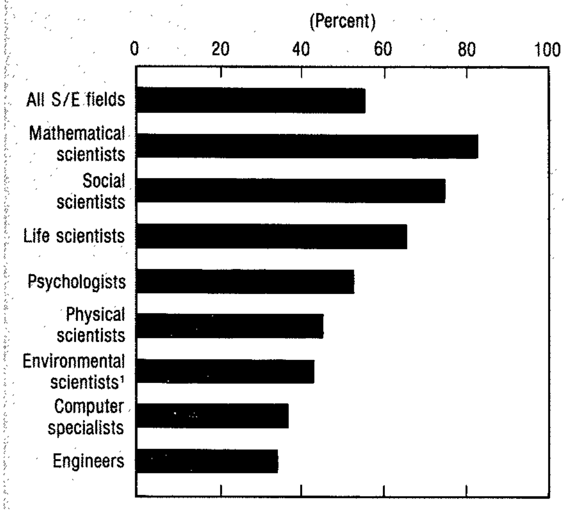
Excluding employed graduate students and S/E's employed in elementary and secondary schools, about 85 percent of the S/E's in educational institutions are in 4-year colleges and universities. Of those, about three of every four hold the doctorate.[13] Because of their numerical importance and because of the scientific leadership they provide, the remainder of this section focuses on those S/E's in educational institutions who hold doctorates. About 55 percent of all employed doctoral S/E's are in educational institutions, 60 percent of the scientists and 34 percent of the engineers.

Employment of doctoral level S/E's in educational institutions has not kept pace with the overall growth in the employment of doctoral S/E's. Between 1973 and 1979, employment of these individuals in educational institutions increased by about 34 percent, while total doctoral employment increased by 42 percent. The below average growth in aca-

[12]National Science Foundation, "Academic Scientists and Engineers Increase 3% in 1978," *Science Resources Studies Highlights*, National Science Foundation, (NSF 79-315).

[13]Based on data in *Human Resources for Scientific Activities at Universities and Colleges*, National Science Foundation (NSF 78-318), January 1978, p. 21.

Figure 5-12
Doctoral S/E's in educational institutions as a percent of all employed doctoral S/E's by field: 1979



¹Includes earth scientists, oceanographers and atmospheric scientists.
REFERENCES: Appendix tables 5-3 and 5-23. Science Indicators—1980

demic employment was countered by the increasing numbers of doctoral S/E's finding jobs in business and industry as discussed earlier in this section.

Almost all (96 percent) of the doctoral S/E's employed in educational institutions were in 4-year colleges and universities in 1979. Small numbers were employed in 2-year colleges and precollege institutions.[14] The distribution of doctoral S/E's among the different types of educational institutions has remained relatively constant since 1973.[15]

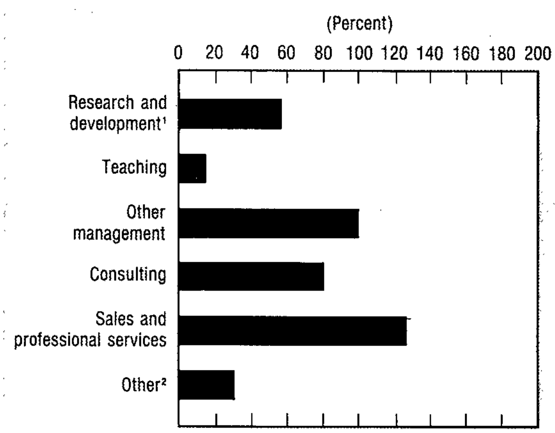
The field distribution of doctoral S/E's in colleges and universities differs from that for all other sectors. There were relatively more scientists and relatively fewer engineers in educational institutions than in other sectors. The proportion of S/E's employed in educational institutions varies considerably by field (see figure 5-12), from 82 percent of the mathematical scientists to 34 percent of the engineers.

Partly reflecting changing course load requirements (enrollments), the field distribution of doctoral S/E's in colleges and universities changed during the 1970's. Employment of physical, mathematical, and environmental scientists grew at below average rates, while employment of social scientists and computer specialists increased at above average rates. Along with the changing field distributions, the work activities of doctoral level S/E's have changed. Those reporting teaching as their primary activity increased by only 15 percent between 1973 and 1979, while the number reporting R&D as their primary activity increased by over 50 percent (see figure 5-13).

Areas of Concern

Within colleges and universities, there are a number of concerns that center on declining opportunities for tenure track appointments for recent doctoral S/E's and the implications of this decline on research vitality. Indicators used to examine these concerns show that the proportion of doctoral S/E's under 35 years of age has declined and the number on postdoctoral appointments more than doubled between 1973 and 1979. In addition, over two-thirds of the full-time S/E faculty hold tenure and, in 1979, the tenure approval rate (those granted tenure as a percent of those considered for tenure) was about 64 percent. The indicators examined below show some loss of young scholars to academia with possible impediments to research progress.

Figure 5-13
Percent growth in primary work activity of doctoral S/E's in educational institutions from 1973 to 1979



¹Includes management of R/D.
²Includes production/inspection, report writing, other and those who did not report their primary work activity.
REFERENCE: Appendix table 5-23. Science Indicators—1980

[14] About two-thirds of the doctoral S/E's in elementary and secondary schools were psychologists.

[15] Unless otherwise noted, the term "colleges and universities" and "educational institutions" will be used interchangeably in the remainder of this section.

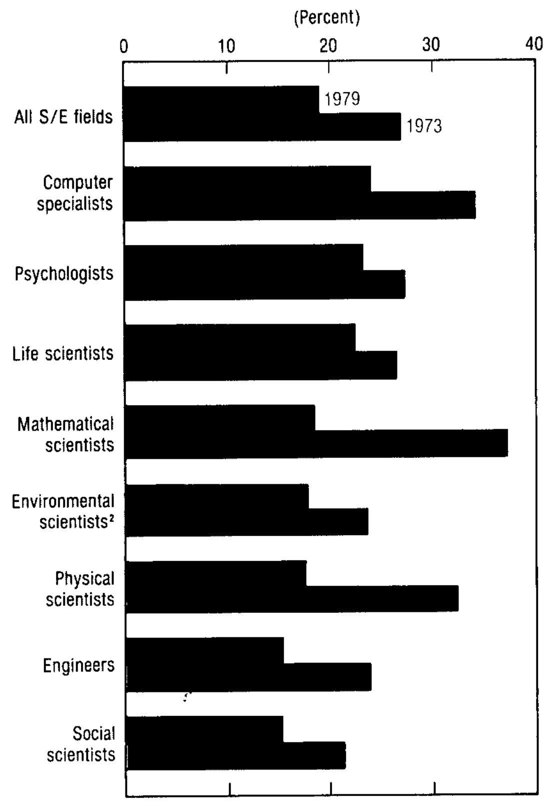
Age Distributions. Concern over the age distribution of academic S/E's stems in part from concern over research vitality.[16] Some believe that young doctorates are more productive than their senior colleagues. Although there is little convincing evidence of a causal link between age and research productivity, young doctorates are acknowledged to have a special role in the dissemination of emerging scientific methods, and a loss of young scholars could impede research progress.[17] Since most researchers in academia have doctorates, indicators illuminating this issue will concentrate on them.

The proportion of doctoral S/E's under 35 years of age has declined in educational institutions from 27 percent in 1973 to 19 percent in 1979. Declines in the proportion of doctoral S/E's under 35 years of age were not uniform across the fields of science. In the physical sciences, the proportion declined from 32 percent to 17 percent between 1973 and 1979, while for environmental scientists the decline was from 23 percent to 18 percent. Generally, those fields showing below average employment growth also showed relatively large declines in the proportion under 35 years of age.

Within educational institutions, the proportion under 35 years of age varies by major field, ranging from 15 percent among engineers and social scientists to 23 percent for psychologists. Strong employment opportunities for engineers in the industrial and other nonacademic sectors may account for the relatively low proportion of engineers under 35 years of age in universities and colleges (see figure 5-14).

Figure 5-14

Distribution of young doctoral S/E's[1] employed in educational institutions by field



[1]Those under 35 years of age as percent of each field.
[2]Includes earth scientists, oceanographers and atmospheric scientists.
REFERENCE: Appendix table 5-24. Science Indicators—1980

Postdoctorates. The decline in the proportion of doctoral level S/E's under 35 years of age in educational institutions becomes more significant when viewed in light of the rapid increase in the number of S/E's holding postdoctoral appointments.

To the extent that some Ph. D.'s prefer to work in academia, poor employment opportunities there may help explain the increase in the number of S/E's holding postdoctoral appointments, which almost doubled between 1973 and 1979 from 5,700 to 10,200.[18] The growth in the number on postdoctoral appointments, however, slowed considerably between 1977 and 1979, increasing by only about 4 percent. Over the 1973-77 period, the total number of doctoral S/E's under 35 years of age remained relatively constant at 35,000. By 1979, it had declined slightly to 33,000. The proportion of those on postdoctoral appointments increased from 16 percent to 28 percent between 1973 and 1977 and to 31 percent by 1979.

The field distribution of those on postdoctoral appointments differs from the field distribution of all doctoral S/E's in educational institutions. That is, the number holding postdoctoral appointments in a particular field is not necessarily related to the total number employed in that field. For example, in 1979 about 12 percent of the life scientists in educational institutions were on postdoctoral appointments, compared to less than 1 percent of the computer specialists (see figure 5-15).

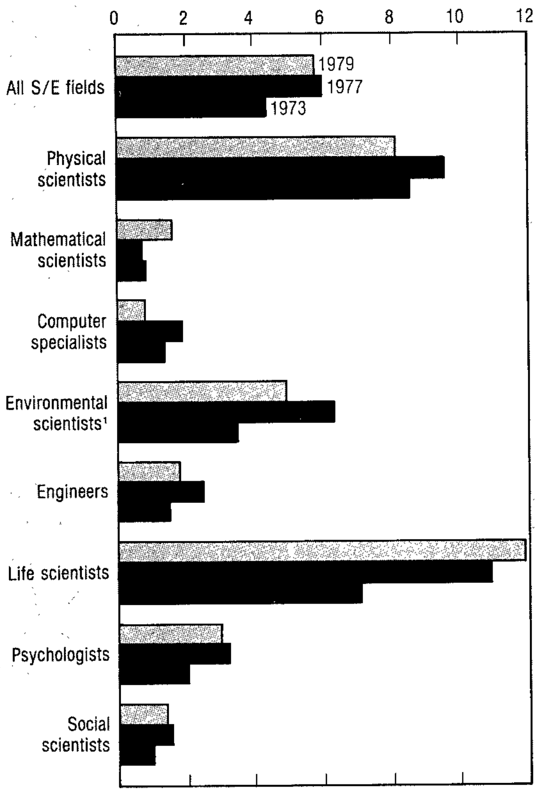
In general, few engineers, psychologists, and social scientists hold postdoctoral appointments,

[16]*Research Excellence Through the Year 2000: The Importance of Maintaining a Flow of New Faculty into Academic Research,* (Washington, D.C.: National Academy of Sciences, 1979). See especially chapter 3, pp. 53-60.

[17]Ibid.

[18]Approximately 82 percent of all those holding postdoctoral appointments in 1979 were in educational institutions. In addition, there were 6 percent in hospitals, 5 percent in nonprofit institutions, 5 percent in the Federal Government, and about 1 percent in business and industry.

Figure 5-15
Postdoctorates as percent of doctoral S/E's employed in educational institutions



¹Includes earth scientists, oceanographers and atmospheric scientists.
REFERENCES: Appendix tables 5-4 and 5-23. Science Indicators—1980

the highest tenure rate (76 percent), while the lowest rate, 64 percent, was observed among social science faculties.

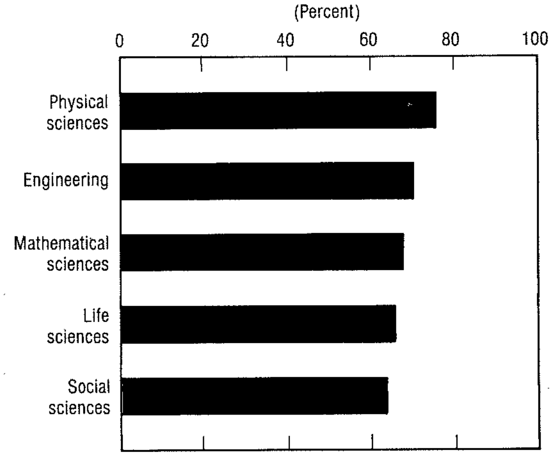
Approximately 2,900 full-time faculty members were considered for tenure in 1978-79. The overall tenure approval rate was 64 percent, only slightly lower than the tenure rate for all S/E faculty, with substantial variation by field (see figure 5-17). Of those not awarded tenure, nearly 7 out of 10, almost all from public institutions, were considered eligible for reconsideration.

The discussion above pertains only to full-time faculty at colleges and universities. A somewhat different, and in some respects fuller, picture develops when doctoral S/E's, regardless of faculty status, are examined. The principal difference in tenure status among all doctoral S/E's involves those in nontenure track positions (15 percent vs. 6.6 percent of full-time S/E faculty). The relatively larger proportion in nontenure positions reflects several factors including: (1) those on postdoctoral appointments; (2) the inclusion of employees of university-administered federally funded R&D centers; and (3) employment of part-time personnel. Recently, part-time employment has been increasing at a substantially faster rate than full-time employment. Between 1977 and 1979, for example, full-time employment of S/E's at doctoral-granting institutions increased by 7 percent, while part-time employment increased by almost

reflecting to some degree traditional patterns of postdoctoral appointments and, for engineers, strong employment opportunities outside universities and colleges.

Tenure status. According to a recent study,[19] there were approximately 123,000 full-time S/E faculty at 4-year colleges and universities in 1979. Of these, about 83,000 or 67 percent held tenure. An additional 26 percent were in tenure track positions but did not yet have tenure. The remainder (6.6 percent) were in nontenure track positions. The proportion of faculty holding tenure varies by field (see figure 5-16). Physical science faculty had

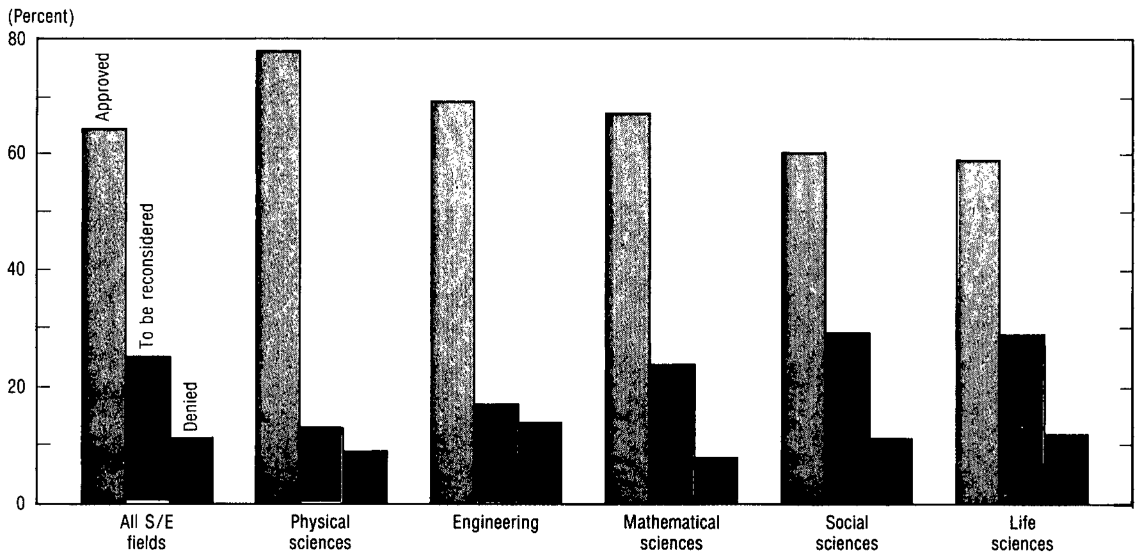
Figure 5-16
Proportion of full-time faculty holding tenure by field: 1978/79



SOURCE: Frank J. Atelsek and Irene L. Gomberg, *Tenure Practices at Four-Year Colleges and Universities*, Higher Education Panel Report Number 48 (Washington, D.C.: American Council on Education, 1980), p. 19.
Science Indicators—1980

[19]See Frank J. Atelsek and Irene L. Gomberg, *Tenure Practices at Four-Year Colleges and Universities* (Washington, D.C.: American Council on Education, 1980).

Figure 5-17
Tenure approval rates of S/E university faculty by field: 1978-79



SOURCE: Frank J. Atelsek and Irene L. Gomberg, *Tenure Practices at Four-Year Colleges and Universities*, Higher Education Panel Report Number 48 (Washington, D.C.: American Council on Education, 1980), p. 19.
Science Indicators—1980

11 percent.[20] The increase in employment of part-time personnel was due primarily to economic and demographic factors.[21] Declining rates of growth in enrollments, beginning in the late sixties, have forced educational institutions to adjust to declines in the number of full-time tenure postions. Part-time faculty represent a more flexible personnel resource than full-time faculty since they are often less costly to employ and generally are in nontenure track positions.

In summary, within academia, concern centers around declining permanent employment opportunities and the implications of these declines on research vitality. Although there is little convincing evidence of a causal link between age and research productivity, young doctorates are acknowledged as having a special role in the dissemination of emerging scientific methods, and a loss of young scholars could impede research progress. Indicators used to examine these concerns show that the proportion of doctoral S/E's under 35 years of age has declined and the number on postdoctoral appointments more than doubled between 1973 and 1979. Over two-thirds of the full-time S/E faculty hold tenure, and in 1979 the tenure approval rate was about 64 percent, suggesting some loss of young scholars to academia and possible impediments to research progress.

LABOR MARKET INDICATORS

Recent concerns over suitable job opportunities for scientists and shortages of engineers and computer specialists suggest a potential maldistribution of resources in the labor markets for S/E's and a need for indicators to assess supply/demand conditions. Standard labor market indicators of supply/demand conditions include unemployment rates and relative salaries. In addition to these, a new measure, the S/E utilization rate, has been developed to help assess both the market for scientists and engineers to work in S/E jobs and the extent to which those with training in science and engineering are utilizing their training in S/E jobs.

Related to supply/demand conditions for all S/E's are concerns focusing on the roles and progress of women and racial minorities in science and engineering. In addition to standard labor market indicators, the roles and progress of women and racial minorities in science and engineering can be par-

[20] *Academic Science: Scientists and Engineers January 1979*, National Science Foundation (NSF 79-328), pp. 5-6.

[21] David A. Katz and Harold P. Tuckman, "Part-timers in the Seventies—A Trend in Academia," unpublished paper, 1978.

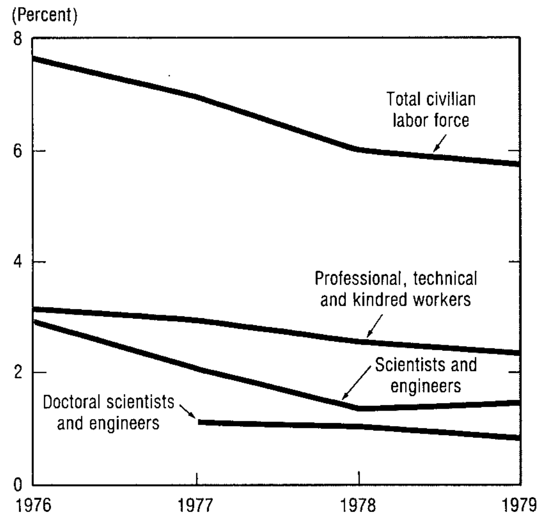
tially indicated by comparisons to all professional and technical workers in the general population.

The indicators examined below reveal consistent patterns of shortages of engineers and computer specialists, hence little underutilization, and ample supplies of social and life scientists. The market for physical scientists has been improving, and supply and demand are in rough balance.

The indicators also suggest that both women and minorities are underrepresented in the science and engineering work force. However, women may be improving their representation, as evidenced by the increasing fraction of S/E degrees granted to them. This increased relative "flow" of new women entrants is slowly altering the sex composition of the stock of scientists and engineers. In contrast, the new entrants "flow" remains relatively low among minorities.

Projections of future supply/demand conditions suggest that, overall, the U.S. will not be constrained from engaging in new initiatives in R&D and other technological efforts based on the availability of human resources. The growing disparity between supply and utilization in some S/E occupations and the potential continuation of shortages of engineers and computer specialists may be cause for concern.

Figure 5-18
Unemployment rates



SOURCES: *Economic Report of the President*, January 1980, p. 237; *Employment and Earnings*, Bureau of Labor Statistics (DOL) January 1980, Vol. 27, no. 1, p. 167; and appendix tables 5-1, 5-2, 5-3 and 5-4.
Science Indicators—1980

Unemployment Rates

A standard measure of labor market conditions is the unemployment rate. Relative to both the general labor force and all professional and related workers, S/E's have shown an improved and relatively strong labor market position (see figure 5-18). In 1971, the unemployment rate for scientists and engineers was 90 percent of that for all professional and technical workers. By 1979, the rate for S/E's had fallen to about 60 percent of that for all professional workers (see appendix table 5-25). The unemployment rate for S/E's declined from 3.0 percent in 1976 to about 1.5 percent in 1979.[22] Occupations showing relatively low unemployment rates—engineers and computer specialists—are those not normally requiring a graduate degree for entry and that are less dependent for employment opportunities on faculty appointments and levels of R&D funding.

S/E Utilization Rates

Unemployment rates are imperfect indicators of market conditions for S/E's for several reasons. These rates do not measure the difficulty in obtaining employment for the first time or for those changing jobs, or the amount of possible underutilization of S/E's in positions requiring skills below those that the job holders actually possess. Most importantly, unemployment rates do not indicate how successful those with education and training in science or engineering are in finding jobs in these fields. While a high unemployment rate indicates that S/E's are having difficulty in finding jobs, a low rate does not mean that they have found jobs in their area of expertise.

To help measure the relative market conditions for scientists and engineers to do science and engineering work, a new indicator, the S/E utilization rate, has been developed that measures the degree to which those S/E's who are working in any occupation or looking for work have jobs in science and engineering.[23]

In 1978, the S/E utilization rate was 83 percent, down slightly from the 1976 rate (85 percent), with considerable variation by field (see figure 5-19). The decline was accounted for entirely by scientists

[22]S/E personnel data for 1979 are preliminary estimates developed by the National Science Foundation.

[23]That is, $\frac{S/E}{LF} \times 100$,

where S/E is the number holding jobs in science and engineering, and LF is the number in the total labor force that includes those S/E's employed in any job and those seeking employment of any kind.

whose rate declined from 82 percent to 73 percent over the 1976-78 period. The rate for engineers increased from 89 percent to 93 percent.

Doctoral S/E's showed a slightly higher S/E utilization rate than all S/E's combined. In 1979, the rate for Ph. D.'s was 91 percent, with some variation by field (see figure 5-19). Variations among Ph. D.'s, however, were less than among all scientists.

Several inferences can be drawn from these indicators. The demand for engineers, computer specialists, and environmental and physical scientists is stronger than the demand for mathematical, life, and social scientists. Among science fields, the demand for those with doctoral degrees is generally stronger than the demand for those at other degree levels.

Relative Salaries

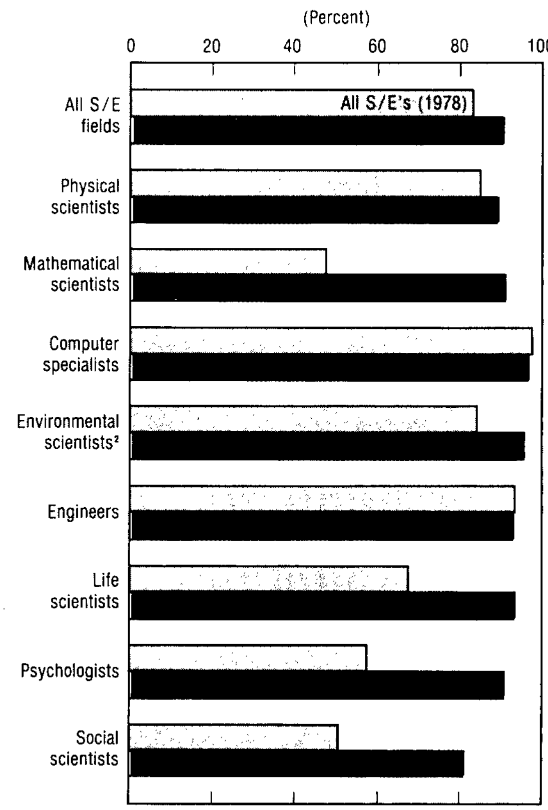
Salary trends are another way of ascertaining labor market balance. If S/E's are in short supply, their salaries would be expected to increase relative to some general salary measure as employers increase their salary offers to attract the available supply. If salaries of S/E's increase at the same or lower rates than do general salary levels, the inference is that the available supply is equal to or greater than current demand for all personnel.

Starting salaries for new hires or inexperienced scientists and engineers are thought by some to reflect the market situation for a particular occupation.[24] Starting salaries for a particular occupation are more sensitive to supply/demand conditions than salaries of experienced persons in that occupation. However, care should be used in drawing inferences from changes in starting salaries. If they are increasing from a generally lower base, the increases may reflect adjustments in overall salary levels. Also, the number of offers made should be considered. For example, while salaries were up in the humanities, the number of offers were down, indicating that the demand for those with degrees in the humanities was not strong (see appendix table 5-29).

Starting salary offers for science and engineering graduates are generally higher than those for graduates in other fields (see figure 5-20). Also, they have increased since the 1976-77 recruiting period, indicating a relatively strong demand for recent graduates in several fields. Median monthly salary offers to computer science majors (and mathematics majors) at the bachelor's level increased by about 25 percent between 1977 and 1979, while the increase for various engineering majors ranged between 18 percent and 22 percent. Among engineers, those majoring in electrical engineering showed the greatest increase in starting salary offers. In contrast, salary offers to biological and social science majors increased by only 15 percent. These data imply that the market for physical scientists, computer specialists, and engineers at the bachelor's level is strong relative to that for graduates in other science fields (see figure 5-20).

NSF data also show that annual salaries for recent S/E graduates increased at a annual rate of 11 percent between 1976 and 1978, from $13,000 to

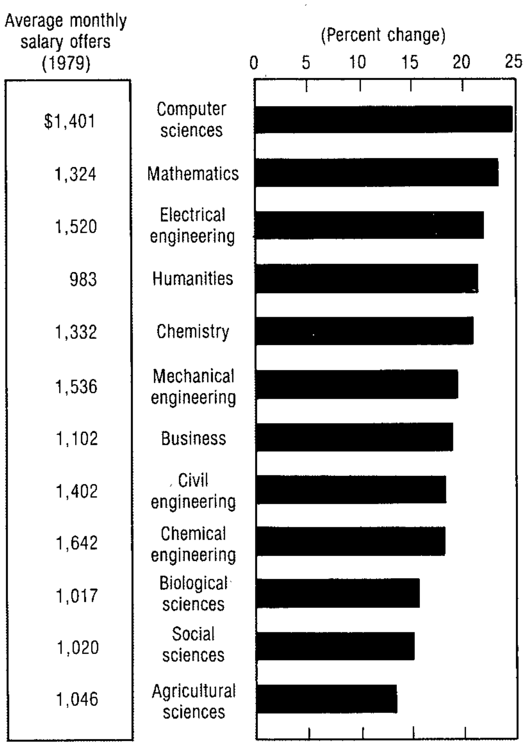
Figure 5-19
S/E utilization rates[1] by field



[1]Defined as those S/E's employed in science and engineering as a proportion of the labor force.
[2]Includes earth scientists, oceanographers and atmospheric scientists.
[3]Includes postdoctorates.
REFERENCE: Appendix table 5-27. Science Indicators—1980

[24]See, for example, W. L. Hansen, "The Shortage of Engineers," *Review of Economics and Statistics*, vol. 43 (August 1961), pp. 251-256; Richard Freeman, The *Overeducated American* (New York: Academic Press, 1976), pp. 10-16.

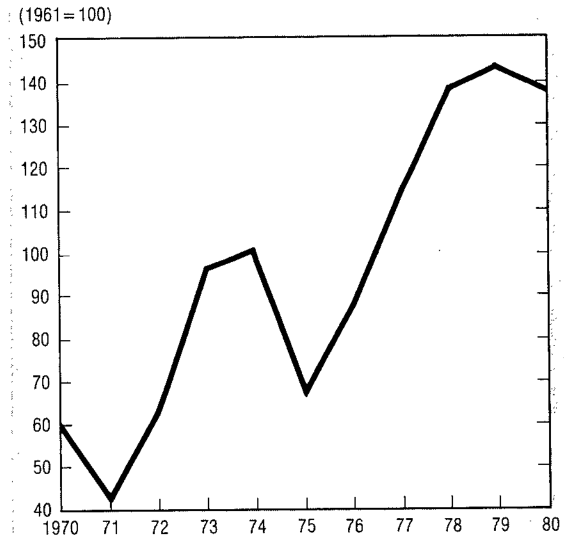
Figure 5-20
Average monthly salary offers to bachelor's degree candidates in selected fields and percent growth between 1977-1979 for selected fields



REFERENCE: Appendix table 5-28.

Science Indicators—1980

Figure 5-21
Deutsch/Shea/Evans High Technology Recruitment Index (HTRI)



REFERENCE: Appendix table 5-31.

Science Indicators — 1980

$16,000. Between 1976 and 1978, annual salaries of experienced S/E's rose from $23,000 to $27,200, an annual increase of about 8.7 percent,[25] which was slightly greater than the increase in the consumer price index over the same period. Over the 1977-78 period, salaries for male professionals increased by 8.3 percent,[26] and hourly rates for factory workers increased by a similar amount (8.4 percent).[27]

[25]Experienced S/E's are defined as those who were in the labor force at the time of the 1970 census of the population. *Characteristics of Experienced Scientists and Engineers 1978*, National Science Foundation (NSF 79-322), table B-33; *Characteristics of Experienced Scientists and Engineers*, Appendix B, National Science Foundation (NSF 78-305), table B-30.

[26]Based on earnings of year-round, full-time workers. See *Current Population Reports*, Series P-60, U.S. Department of Commerce, Bureau of the Census, No. 120 (November 1979), p. 18.

[27]*Employment and Training Report of the President, 1979*, U.S. Department of Labor, p. 322.

Other Indicators

Another indicator of market conditions for particular S/E personnel is the level of college recruitment at the bachelor's degree level. Recipients of an engineering bachelor's degree received almost 80 percent more offers (not necessarily acceptances) between 1977 and 1979.[28] The most sought-after specialties, in order of demand, were electrical (including computer engineering), mechanical, chemical, and civil engineering. The 36-percent increase in offers to science graduates reflected, primarily, a 70-percent increase in offers to computer science majors. The humanities and social science groups combined had 14 percent more offers (see appendix table 5-29).

The High Technology Recruitment Index (HTRI) is another indicator of current market conditions for S/E's. The HTRI measures the amount of advertising space dedicated to recruiting scientists and engineers. In 1970 the index measured 60 (1961=100). In 1977 the index began a steady increase (see figure 5-21). However, demand (as measured by the HTRI) may have peaked. For 1980, it dropped to 138 from a 10-year high of 144 in 1979.[29]

[28]*CPC Salary Survey Final Report* (Bethlehem, Pa.: College Placement Council, July 1977 and 1979), p. 3.

[29]"High Technology Recruitment Index Year End Review and Forecast," (New York: Deutsch, Shea & Evans, Inc., 1981).

These indicators show consistent patterns of shortages of engineers and computer specialists and ample supplies of social and life scientists. The market for physical scientists has been improving with supply/demand conditions in rough balance in early to mid-1980.

Women in Science and Engineering

The number of employed women S/E's in 1978 (231,500) represented about 9.4 percent of all employed S/E's, up from 8.3 percent in 1976. Between 1976 and 1978, employment of women scientists and engineers increased at a much faster rate than men's employment (17 percent vs. 3 percent).

Despite this rapid employment growth, women are still underrepresented in S/E jobs when compared to their employment in all professional and related fields. In 1978, women represented about 41 percent of all employed persons, and a slightly higher proportion of all professional and technical workers (43 percent).[30] This latter group includes occupations, such as nursing and teaching, that traditionally employ large numbers of women.

The unemployment rate for women S/E's in 1978 was 2.4 percent, in contrast to the 1.3 percent unemployment rate for male S/E's.[31] The differences in unemployment rates between men and women are not due entirely to differences in field concentrations. With the exception of computer specialists and environmental scientists, unemployment rates for women S/E's were higher than for men S/E's across all fields. However, unemployment rates for women S/E's were lower than the rate for all women in professional and technical fields (3.5 percent),[32] and for all women with 4 or more years of college (3.0 percent).[33] At 2.4 percent in 1978, the unemployment rate for women S/E's represents a considerable drop from the 6.8 percent rate in 1976.

Salary similarities between men and women S/E's could indicate equity in the S/E work force. However, salary differentials reflect many factors, such as field of employment, years of experience, and type of employer. Median salaries for women scientists and engineers averaged 82 percent of those for men, with the male/female differential ranging from a low of 73 percent for social scientists to 90 percent for computer specialists (see figure 5-22). Women scientists and engineers had narrower differentials than did women college graduates in general. During the same year (1978), median salaries for the total population of women college graduates were only 61 percent of the figure for the comparable population of men.[34]

Minorities in Science and Engineering

Only about 4.5 percent of all employed S/E's in 1978 were members of racial minority groups[35] compared to about 9 percent of all professional and related workers.[36] However, employment of minority S/E's has been increasing at a faster rate than employment of white S/E's. Between 1974 and 1978, the number of employed S/E's of Asian extraction increased by 25 percent, while employment of blacks increased by 20 percent. Among white S/E's, the increase was about 10 percent. However, by 1978 blacks still represented only 1.6 percent of all employed S/E's, while Asian-Americans represented 2.0 percent.

Salary similarities between white and racial minority S/E's could indicate equity in the S/E work force. As was pointed out above, however, salary differentials reflect many factors such as field of employment, years of experience, and type of employer. Median salaries for black S/E's averaged 91 percent of those for whites, while salaries of Asian-Americans averaged 95 percent of those for whites (see figure 5-23). Median salaries of all black male college graduates averaged 83 percent of those for white male college graduates in 1978.[37]

Blacks who become S/E's fare about as well as their white colleagues in finding employment. The 1978 labor force participation rate for black S/E's (94.7 percent) was somewhat higher than that for their white counterparts (91.3 percent) and was considerably above the 1978 rate for all blacks in the general population (about 62 percent).[38]

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[30] *Employment and Training Report of the President*, p. 260.

[31] *U.S. Scientists and Engineers 1978*, National Science Foundation, (NSF 80-304), p. 15.

[32] *Employment and Earnings*, vol. 27, No. 1 (January 1980), p. 167.

[33] *Educational Attainment of Workers—Some Trends From 1973 to 1978*, Special Labor Force Report 225, U.S. Department of Labor, Bureau of Labor Statistics, p. A-8.

[34] *Science and Engineering Personnel: A National Overview*, National Science Foundation (NSF 80-316), p. 4.

[35] Minority groups as used in this report include blacks, American Indians, Asian-Americans, and all other minority groups, as well as those not reporting race. Of the estimated 112,000 employed S/E's in 1978 who were members of racial minority groups, about 22,800 or 0.9 percent of the total had not reported their race.

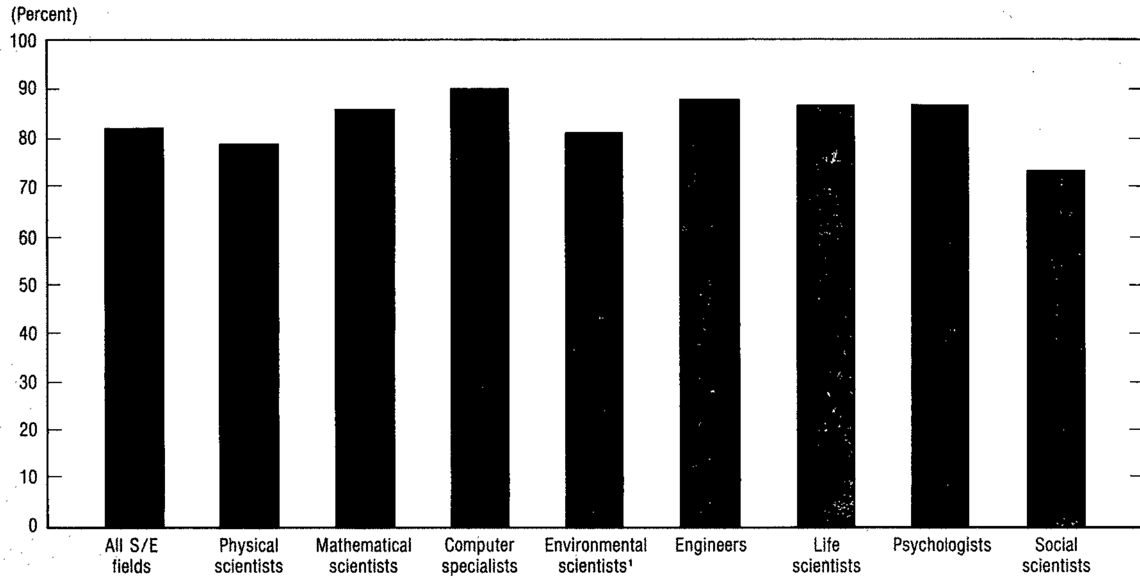
[36] *Employment and Training Report of the President, 1979*, p. 262.

[37] U.S. Department of Labor, Bureau of Labor Statistics, unpublished data.

[38] *Employment and Training Report of the President, 1979*, p. 247, Table A-7.

Figure 5-22

Salaries of experienced women S/E's as a percent of experienced men S/E's salaries: 1978



[1]Includes earth scientists, oceanographers and atmospheric scientists.
REFERENCE: Appendix table 5-32.

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Unemployment rates for S/E's across all races declined substantially from 1976 levels (from 3.0 percent to 1.4 percent). The decline in the unemployment rate among blacks, however, was most dramatic—from 8.3 percent to 1.5 percent. The principal effect of this decline was to bring the rate for blacks into parity with white and Asian-American scientists and engineers.

Persons of Hispanic origin are underrepresented among the doctoral S/E population. In 1979, there were about 2,600 persons of Hispanic origin in the population of doctoral S/E's, representing less than 1 percent of the total. In contrast, almost 5 percent of the population 16 years of age and older claim Hispanic origin.[39] Among those S/E's reporting Hispanic origin, about 86 percent were men and about 80 percent were U.S. citizens.

Projected Labor Market Conditions

Projections are indicators of possible futures generally used to anticipate potential problems and to develop a better understanding of the dynamics of the systems under analysis. Since projections are sensitive to assumptions about behavioral relationships and future values of critical variables, they should be used cautiously.

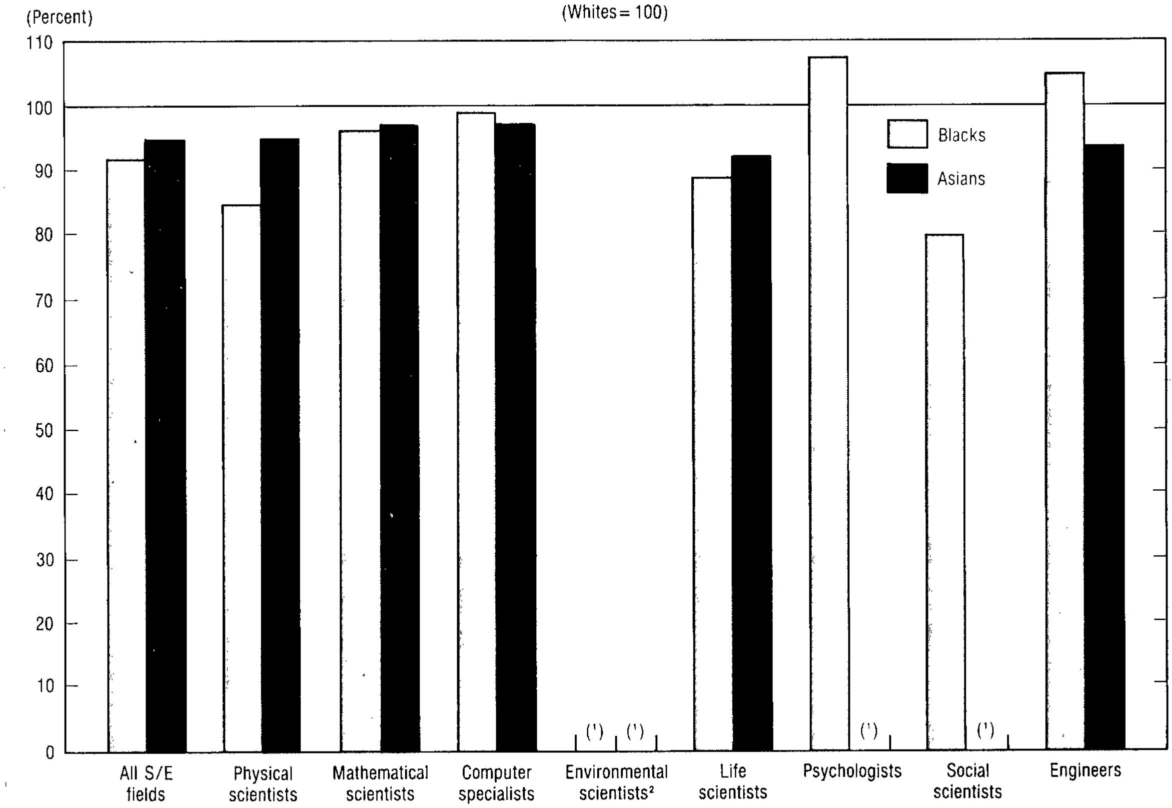
The projections outlined below suggest that, strictly on the basis of the availability of S/E human resources, it is unlikely that the United States will be constrained from engaging in new nitiatives in R&D and other technological efforts. The projected disparity between supply and utilization for doctoral scientists, however, is cause for concern, since there may be some direct loss for the next several years from underutilization of the substantial resources invested in the specific skill training of those scientists who will be working in nonscience or nonengineering activities.

All Scientists and Engineers. In general, the Bureau of Labor Statistics estimates that the supply of scientists through the mid-1980's will be more than adequate to meet demand in most fields. For engineers, supply and demand are expected to be in rough balance. Estimates of adequate supplies of scientists and a rough balance between supply and demand for engineers do not change significantly under differing assumptions for increased defense spending, or specific development of a large scale synthetic fuels program or a balanced Federal budget.

[39]*Employment and Earnings*, vol. 27, No. 1 (January 1980), p. 191.

Figure 5-23

Salaries of experienced black and Asian S/E's as a percent of experienced white S/E's salaries: 1978



¹Too few cases to estimate.
²Includes earth scientists, oceanographers and atmospheric scientists.
REFERENCE: Appendix table 5-32.

Science Indicators—1980

However, if all of these events would occur simultaneously, some shortages could develop.[40] Projections developed by BLS indicate that engineering graduates in most specialties will face good employment opportunities through the mid-1980's.[41] In the Bureau's terminology, the phrase "good employment opportunities" means that supply and demand will be roughly balanced.

The outlook for scientists varies considerably by field and level of training. Favorable employment opportunities are projected for geologists and geophysicists, reflecting increasing exploration for petroleum and other minerals. However, the number qualified to enter the geophysics field may fall short of requirements if current trends continue. In the physical sciences, favorable opportunities are projected in the nonacademic sectors for chemists and physicists. The situation is expected to be less favorable for those seeking employment as astronomers.

Those seeking employment as mathematicians are likely to face competition through the mid-1980's. Opportunities, however, are expected to be best for advanced degree holders in applied mathematics seeking jobs in government and in private industry. Employment opportunities for life scientists are expected to be good for those with advanced degrees through the mid-1980's, but those with lesser degrees may experience more competition

[40]For a more complete discussion of the sensitivity of supply/demand projections to alternative policy assumptions, see *Science and Engineering Education For the 1980's and Beyond* prepared by the National Science Foundation and the Department of Education, October 1980.

[41]See "The Job Outlook in Brief," *Occupational Outlook Quarterly* (Spring 1980), U.S. Department of Labor, Bureau of Labor Statistics.

for available jobs. In the social sciences, anthropologists are expected to face keen competition for jobs, while economists with master's and doctoral degrees are expected to have generally favorable nonacademic opportunities.[42] For sociologists at all degree levels, supply is expected to be greater than demand. For doctoral psychologists, prospects will be brightest for those with training in applied areas such as clinical counseling and industrial psychology.

Doctoral Scientists and Engineers. The annual number of doctorates awarded in science and engineering has declined steadily since 1973, the first such decline experienced since the mid-1950's. These declines, coupled with reduced employment opportunities for scientists and engineers in the academic sector, raise policy issues regarding future supply/demand relationships, market adjustments of imbalances, and potential implications of these for the future vitality of scientific research and development in the United States—particularly in the academic sector.

Independent projections, prepared by the National Science Foundation (NSF) and the Bureau of Labor Statistics (BLS), indicate that, in general, the supply of doctorate scientists and engineers is likely to be more than ample to meet anticipated demand.[43] Depending on the model examined, from 185,000 to 210,000 students are projected to receive science and engineering doctorates from U.S. universities over the next decade.[44] Based on these projections and estimates of attrition, an S/E doctoral labor force of 410,000 to 420,000 is projected for the mid-1980's, compared to 340,000 to 350,000 projected to be in S/E-related (or traditional) activities.

The difference between supply and utilization in the mid-1980's is projected by BLS and NSF to be in the 60,000 to 80,000 range. This difference represents an estimate of the number of doctoral S/E's likely to find it necessary to accept non-S/E or nontraditional employment. Based on historical evidence, probably only a small proportion of this group will actually be unemployed. By contrast, only about 23,000 doctoral S/E's were in non-S/E positions in 1977.

The NSF and BLS models produce some differences in projected supply/utilization findings when the data are classified by broad S/E fields. Mathematics and the social sciences are expected to encounter the largest imbalance, with from 20 percent to 30 percent of doctoral S/E's projected to face potential non-S/E employment. Problems are expected to be somewhat less severe in the life sciences (with 15 percent to 20 percent projected to be in non-S/E activities) and in the physical sciences, where only about 10 percent are projected in non-S/E activities. In considering these non-S/E activity projections, it should be remembered that in 1977 about 8 percent of the S/E doctorates were in non-S/E related jobs. The projections for engineers are more divergent. The NSF model projects that some engineering doctorates will be employed in non-S/E activities, whereas the BLS model projects a shortage in the labor market for doctoral engineers. This difference is primarily due to considerably lower projections of doctorate degrees in engineering by BLS. Although the number earning bachelor's degrees in engineering has been increasing, currently favorable employment opportunities for such engineers might have a negative impact on graduate school enrollments. The diversion of baccalaureate engineers from graduate school was not anticipated at the time the NSF projections were developed.

RECENT SCIENCE AND ENGINEERING GRADUATES

Until the decade of the 1970's, scientists and engineers enjoyed a very favorable status in the post-World War II labor market. However, at the beginning of the 1970's, the "seller's market" for scientists and engineers came to an end, at least temporarily, as a result of several related developments. While large numbers of new scientists and engineers continued to enter the job market, the demand did not keep pace because of a slowdown in real Federal R&D funding, reduced outlays for defense and space-related activities, and a slowdown in enrollment growth in colleges and universities. Moreover, longer term projections of the

[42]For an analysis of the market for new doctoral level economists, see W. L. Hansen et al., "Forecasting the Market for New Ph.D. Economists," *The American Economic Review*, vol. 70 (March 1980), pp. 49-63.

[43]For models of supply and utilization covering scientists and engineers, see *Projections of the Supply and Utilization of Science and Engineering Doctorates, 1982 and 1987*, National Science Foundation (NSF 79-303); Douglas Braddock, "Oversupply of Ph.D.'s to Continue Through 1985," *Monthly Labor Review* (October 1978). Other models related to more general markets for highly trained labor, or to particular sectors of this market (such as academic sector) can be found in Richard Freeman, *The Overeducated American* (New York: Academic Press, 1976); *Projections of Educational Statistics to 1986-87*, U.S. Department of Health, Education, and Welfare, National Center for Education Statistics; Roy Radner and Charlotte V. Kuh, *Preserving a Lost Generation: Policies to Assure a Steady Flow of Young Scholars Until the Year 2000* (Berkeley, Calif.: Carnegie Council on Policy Studies in Higher Education, 1978).

[44]These projections are adjusted to reflect the international flows of migrating scientists and engineers. The BLS projection (185,000) is for the period 1976-85; the NSF projection (210,000) is for the period 1977-87.

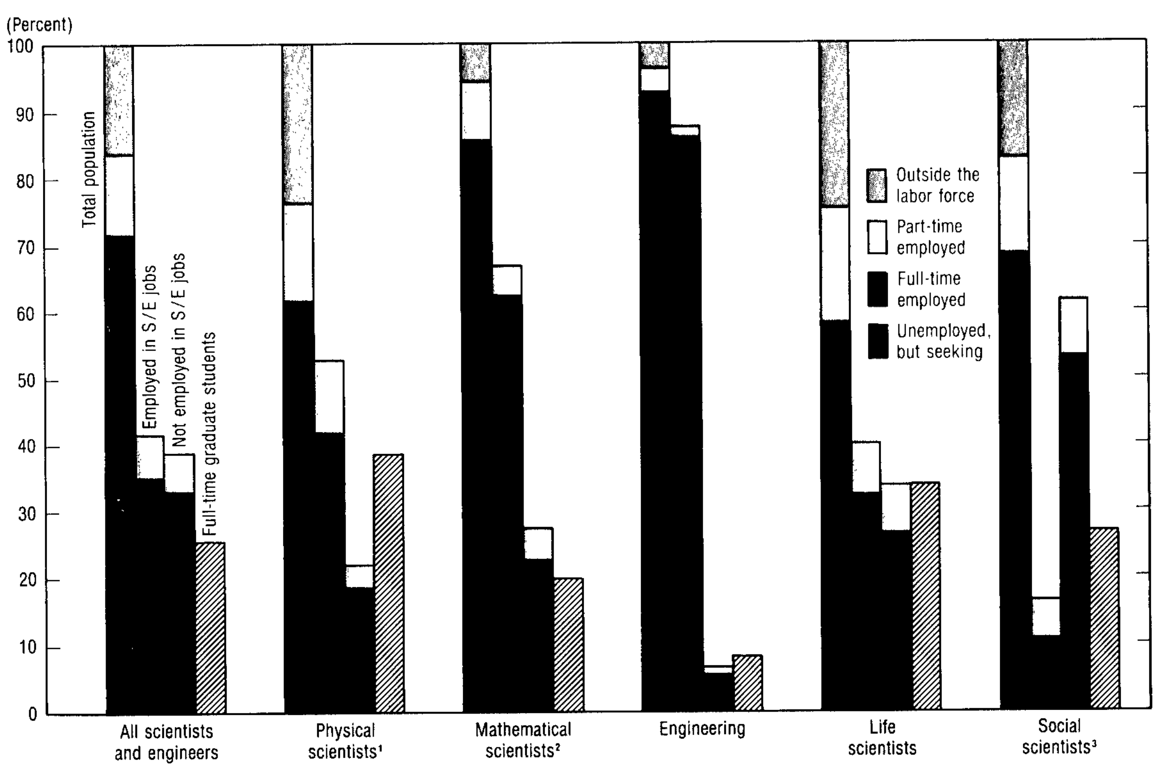
employment outlook for college graduates began to highlight a potential excess in relation to probable demand in the fields in which these graduates had traditionally been employed.

A primary objective of this section is to provide indicators of the transitions from school to work of recent S/E graduates at all degree levels (see figure 5-24). Not only are these data necessary to estimate more fully the current characteristics of the S/E population, but they are also useful as labor market indicators. By revealing the experience of new S/E graduates, these data can provide "early warning signals" of impending shifts in supply as well as insight into the current demand situation. Employment trends for recent graduates provide a sensitive barometer of overall labor market conditions in the various S/E fields, since any changes in employer demand normally are reflected first in employer hiring decisions. In addition, information on labor market conditions can cause students to alter decisions concerning college majors and possible careers.

The indicators presented below show that, for recent graduates, job opportunities were very good in engineering and computer science fields and for physical science graduates with advanced degrees, but relatively less adequate in the life and social sciences. Although overall unemployment rates for recent S/E graduates were relatively low in the late 1970's, labor market conditions vary significantly among major fields, particularly when allowance is made for "underemployment."

Women graduates, as well as blacks, generally showed higher rates of unemployment than did other S/E graduates in the same fields. The labor market difficulties of both women and black graduates were partially due to their concentration in fields such as the social sciences, which have experienced a higher overall incidence of unemployment and underemployment in recent years.

Figure 5-24
Selected employment characteristics of 1977 bachelor's degree recipients: 1979



[1]Includes environmental scientists.
[2]Includes computer scientists.
[3]Includes psychologists.
REFERENCE: Appendix table 5-41.

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Among recent graduates in science and engineering, there was a slight shift towards industrial employment and away from academic employment. The modest decline in employment of recent graduates in academia is expected to continue as demand for new S/E positions is reduced in response to changing demographic conditions. The patterns of work activities of recent graduates have shifted and are characterized by an increase in R&D and teaching activities accompanied by declines in production-related activities and in sales and professional services.

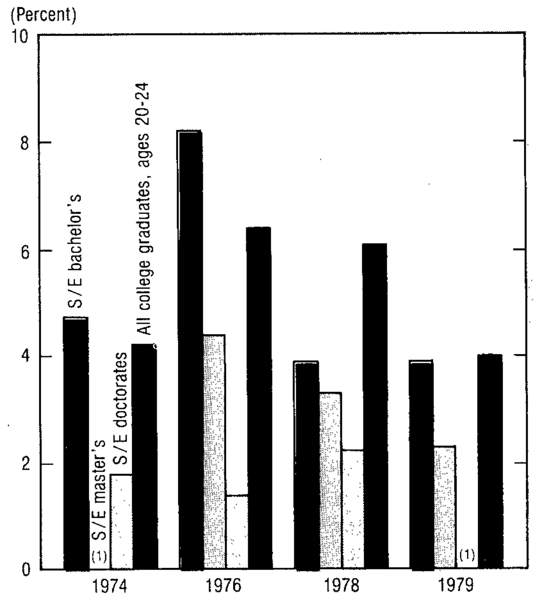
Unemployment

A large proportion of S/E degree recipients normally enter the labor force after graduation in either full- or part-time employment. Of those graduating in 1976 and 1977, approximately 85 percent of the bachelor's degree recipients and 90 percent of the master's degree recipients were in the labor force when surveyed 2 years later. All but a small proportion of those not in the labor force were engaged in full-time graduate study. Labor force participation rates among women S/E graduates were generally as high as for their male counterparts. At the doctoral level, participation rates of approximately 99 percent were reported by recent graduates.

The unemployment rate (i.e. the proportion of those in the labor force not employed but seeking work) is a widely used general indicator of labor market trends. Unemployment rates alone, however, are not necesssarily an accurate indicator of market conditions for S/E's. These rates do not indicate how successful those with training in science and engineering are in finding jobs in science and technology. As expected, unemployment rates among recent S/E bachelor's degree graduates were substantially higher than those reported for all experienced S/E personnel. Since 1976, the unemployment rates for master's degree holders were substantially lower than for those with only bachelor's degrees.

The fluctuations in the unemployment rates for S/E bachelor's degree graduates since 1974 also seem consistent with related data on trends in the S/E labor market and in the general economy. S/E graduates who received their bachelor's degrees in 1974 experienced significant difficulty finding employment, as reflected in an unemployment rate of over 8 percent for this group in 1976 compared to 3 percent for all S/E's. The strong economic recovery during the following years was accompanied by a sharp drop in this unemployment rate to about 4 percent for more recent graduating classes

Figure 5-25
Unemployment rates of recent S/E graduates by degree level and of all college graduates, from 20-24 years of age



[1]Not available.
NOTE: Doctoral data shown as 1974, 1976, and 1978 were collected in 1973, 1975 and 1977, respectively.
SOURCES: National Science Foundation, *New Entrants Surveys*; U.S. Bureau of Labor Statistics, *Special Labor Force Reports on Educational Attainment of Workers*; and appendix table 5-38.

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(see figure 5-25). For all S/E's, the unemployment rate was 1.5 percent in 1979.

However, more detailed analysis indicates wide variations in the job market experiences of graduates in major S/E fields. Among bachelor's degree recipients, the most recent survey data (1978 and 1979) indicated: (1) excellent job opportunities for graduates in engineering and the mathematical sciences whose unemployment rates approximated 1 percent; (2) a good, and substantially improved, job market for physical science graduates, whose unemployment rate dropped from nearly 5 percent in 1978 to about 2.5 percent in 1979; (3) a somewhat "softer" job market in the life sciences, where unemployment rates hovered at approximately 4 percent in both 1978 and 1979; and (4) a deteriorating job market for graduates in the social sciences, whose unemployment rate rose from 5 percent in 1978 to 6 percent in 1979. Although 1978 and 1979 unemployment rates for master's graduates in the physical and life sciences were consistently lower than the corresponding rates for bachelor's graduates

in these fields, this pattern did not apply to the other major fields.

S/E Employment Rate

One measure of potential underutilization of recent science and engineering graduates is the percentage of recent graduates employed in S/E positions. These percentages have varied widely by degree level and field. A high rate of S/E utilization indicates "tight" S/E labor markets. A low rate indicates "soft" S/E labor markets and may represent a more pervasive pattern of underutilization. One-half or less of the bachelor's degree graduates, and three-fourths of the master's degree graduates, who were employed, reported that they were in S/E jobs in each of these survey years (1976, 1978, and 1979) for which comparable data are available. Among the major fields, the proportions in S/E jobs were consistently highest for engineering graduates and lowest for social science graduates, particularly at the bachelor's level (see appendix table 5-41).

One of the factors contributing to the low overall proportions of recent S/E graduates holding S/E jobs is that for some science fields, the entry level may be the master's degree rather than the bachelor's degree. Thus, relatively few recent graduates at the bachelor's level find employment in their fields or in other science occupations. To some extent, employers may be "screening" by level of education because the supply greatly exceeds the demand. However, an increase in the educational level necessary to enter the field also may reflect informed opinion that, generally, graduate education is necessary to do professional work in a field. To be included as a scientist or engineer in the general NSF estimates, a recent graduate must hold a master's degree in mathematics, the biological sciences, psychology, or the social sciences, or hold a bachelor's degree in any of these fields and be employed in a science or engineering job; or hold a baccalaureate in any other S/E field such as engineering or computer science. The decision to "count" only those who hold a master's degree in certain fields is based on an analysis of the proportion of those earning bachelor's degrees who find science or engineering employment. If that proportion is less than 50 percent, only those with a master's degree are counted, unless the individual's employment is in science or engineering. Discussions with professional societies support this decision.

Although these statistics offer a useful measure of the degree of nonutilization of the specialized training of graduates in S/E fields, they do not provide a complete measure of inadequate S/E job opportunities. Some non-S/E employment was due to preference or other personal reasons, rather than to lack of S/E job opportunities. Also, a low S/E utilization rate does not necessarily reflect underutilization from a societal perspective, although it does indicate, at least in part, a loss to science and technology.

Underemployment

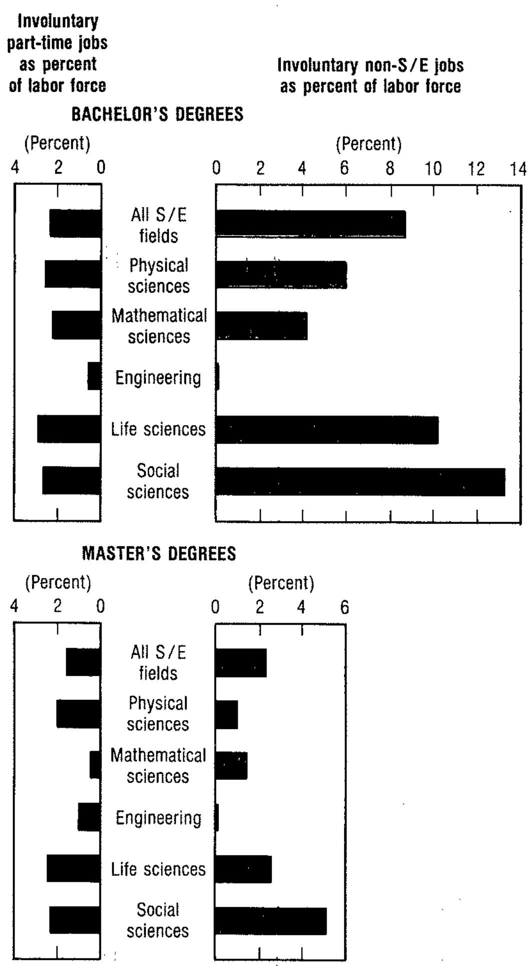
Unemployment rates are only partial indicators of the extent to which the labor market has provided adequate opportunities for recent S/E graduates to utilize their training and skills. A more extensive indicator of those conditions is the degree of underemployment experienced by recent graduates. When full-time jobs in their fields of specialization or in other science and engineering fields have not been available, many S/E college graduates have accepted either part-time jobs or positions outside science and engineering—in preference to remaining unemployed. Thus, relatively low unemployment rates may conceal significant problems of underemployment.

There are two categories of underemployed graduates. The first consists of persons employed part time, who report that they are seeking full-time work. The incidence of this form of underemployment was relatively low among recent (earning degrees in 1977) S/E graduates in 1979, averaging about 2 percent for both bachelor's and master's degree recipients.

The second, and larger, category includes all graduates who are not adequately utilizing their specialized S/E training in their current positions. Thirty-four percent of all recent bachelor's degree graduates in the labor force and 16 percent of those with master's degrees reported in 1979 that they were holding positions not related to science and engineering. However, an analysis of reported reasons for non-S/E employment indicates that only a modest fraction of the latter groups were employed involuntarily in non-S/E positions (see appendix table 5-7). Of those employed in non-S/E positions, over half of all of the bachelor's degree graduates and nearly two-thirds of those with master's degrees indicated that they preferred non-S/E jobs, while some offered other reasons for this choice such as better pay or promotional opportunities. Those who were voluntarily in non-S/E positions reported annual salary rates closely approximating those of their fellow graduates holding S/E jobs. In contrast, those graduates who reported that they were employed involuntarily in non-S/E positions, i.e., "because an S/E job was not available," received salaries that averaged about 37 percent less than the average salaries for those holding S/E positions. Based on salary, it appears

Figure 5-26

Underemployment among recent science and engineering graduates by degree level and field of degree: 1979



REFERENCE: Appendix table 5-39.

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reasonable to limit the definition of the underemployed group to those involuntarily in non-S/E positions.

Under this more restrictive definition, nearly 9 percent of all bachelor's degree graduates and 2 percent of those with master's degrees were being underutilized in their current positions, due to the unavailability of S/E positions in 1979 (see figure 5-26). The extent of underutilization varies widely among major S/E fields, closely paralleling the variations in unemployment rates. Thus, among bachelor's degree graduates, the percentage involuntarily in non-S/E employment was negligible among engineering graduates in contrast to much higher rates among those in the life sciences (10 percent) and social sciences (13 percent). Similarly, among master's degree recipients, underutilization was most frequently reported by social science graduates.

These underutilization rates, when combined with the rates of unemployment and involuntary part-time employment, provide a more comprehensive indicator of the adequacy of job opportunities for recent S/E graduates than do unemployment rates alone. Thus, even in 1979, a year of relatively high aggregate labor demand, 22 percent of all bachelor's degree graduates in the social sciences and 17 percent in the life sciences were either unemployed or underemployed. In contrast, only 2 percent of all engineering graduates and 7 percent of those in the mathematical sciences were not being adequately utilized under these criteria. Despite the much more favorable overall job experience of the master's degree recipients, 7 percent of the life scientists and 11 percent of the social scientists were also unemployed or underemployed in 1979, compared to much lower proportions in the other major fields. In the market for recent doctoral S/E's, the incidence of involuntary part-time employment has been quite low and generally parallels the level and movement of the overall unemployment rates of this group.

Salaries

An additional indicator of trends in the job market for S/E graduates is provided by the trend in salaries offered to bachelor's degree candidates in various academic fields. Weighted average salary offers were derived for each of the five major S/E fields for two years—1973-74 and 1978-79.[45] The percentage changes over this 5-year period indicate a sharp contrast in salary trends: monthly salary offers in the physical and mathematical sciences and in engineering—the fields with the most favorable recent job market conditions, based on the NSF survey data—experienced relatively rapid salary growth, compared to much lower percentage increases in the life sciences and the social sciences, the fields with the highest incidence of unemployment and underemployment. These differential salary trends provide additional confirmation of the sharp contrast in recent job opportunities among graduates in the various S/E fields.

[45]Harold Wool, "The Adequacy of Job Opportunities for Recent Science and Engineering Graduates," *Paper Commissioned as Background for Science Indicators—1980*, Vol. V, National Science Foundation, 1981.

Women S/E's

Despite a rapid growth in the proportion of women graduates in nearly all fields of science and engineering during the past decade, women continue to be highly concentrated in the social and life sciences. These two fields accounted for about 80 percent of women S/E graduates at all degree levels in the 1977-78 academic year.

A comparison of the unemployment rates for recent men and women graduates indicates that women S/E graduates at all degree levels have significantly more labor market difficulty than their male counterparts (see figure 5-27).

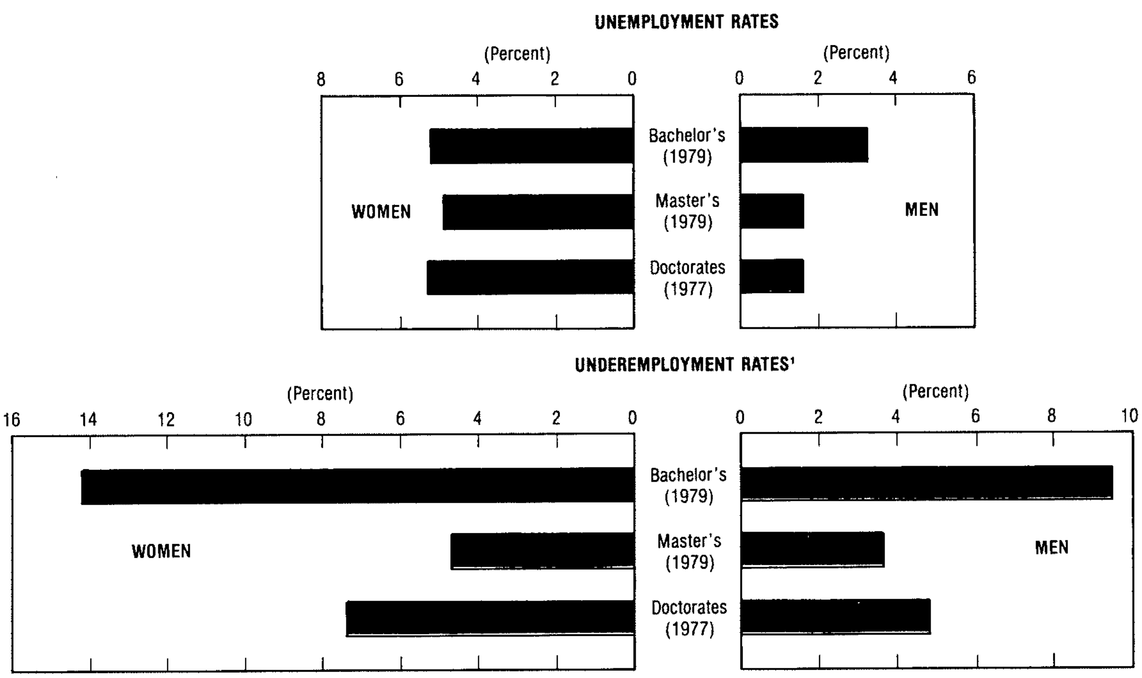
These general comparisons are affected by the concentration of women graduates in the social and life sciences—fields in which the job market has been less favorable in the past several years. On a field-specific basis, the extent of adverse employment experiences for women graduates, compared to men, was more variable. For example, among 1977 bachelor's degree graduates surveyed in 1979, women experienced substantially higher unemployment rates than men in the physical and life sciences and a slightly lower rate in the mathematical sciences.

The most recent data on underemployment also indicate a more difficult overall labor market situation for women S/E graduates, particularly at the bachelor's degree level. However, although underemployment rates for women are higher than for men in both the social sciences and the physical sciences, women graduates in the life sciences reported a lower incidence of involuntary employment outside of science or engineering than among male life science graduates.

In addition to experiencing more difficulty in obtaining suitable full-time jobs, women who were employed full time generally received somewhat lower salaries than did men from the same graduating classes. The average salary of all recent women S/E graduates in 1979 was 23 percent below that of men at the bachelor's degree level and 25 percent lower among master's degree recipients. However, these differences are also due in large part to the

Figure 5-27

Unemployment and underemployment rates for recent S/E graduates by sex and degree level

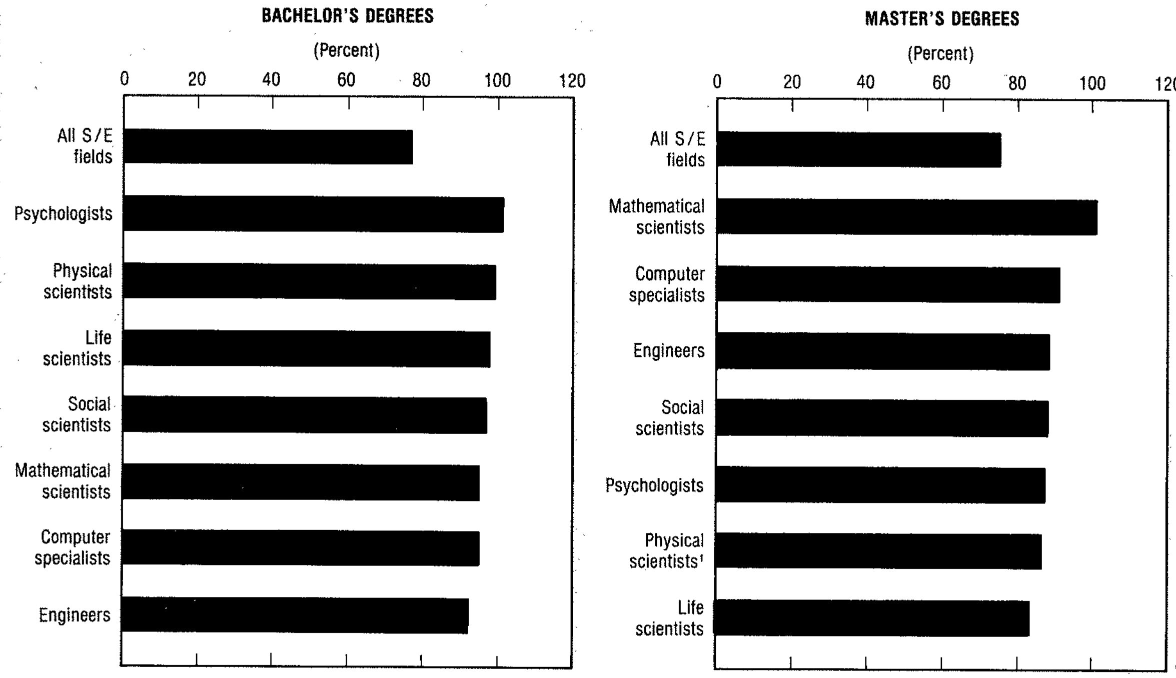


[1]Underemployment rates for bachelor's and master's degree graduates include part-time workers seeking full-time jobs and persons employed full-time in non-science and engineering jobs for whom an S/E position was not available. Underemployment rates for doctorates include part-time workers seeking full-time jobs and those employed full-time outside of their doctoral field for whom positions in their field were not available. These rates are therefore *not* comparable to the corresponding rates for bachelor's and master's degree graduates.

REFERENCE: Appendix table 5-40.

Science Indicators—1980

Figure 5-28
Recent female S/E graduates employed full-time as a percent of those for recent male S/E graduates, by degree level and field: 1979



REFERENCE: Appendix table 5-44.

Science Indicators—1980

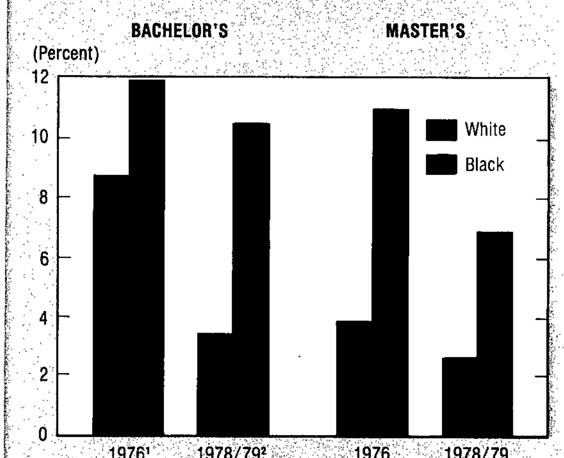
concentration of women S/E graduates in the social and life sciences where salary levels have been consistently below those in engineering or the physical sciences.

Among the 1977 bachelor's degree graduates, the 1979 median annual salary of women was approximately the same as that of male graduates in two fields (physical science and psychology) and ranged from only 2 percent to 8 percent below the corresponding salaries for men in the remaining fields. Among 1977 master's degree recipients, women's salaries, in 1979, equaled those of men in the mathematical sciences, but ranged from 8 percent to 17 percent below male salaries in the other S/E fields (see figure 5-28).

Black S/E's

In recent years, there has been an increase in the proportion of blacks among S/E bachelor's degree graduates, from 2.5 percent in the academic years 1974 and 1975, to 4.2 percent in the following 2 years, representing an absolute increase of almost 50 percent. The proportion of black master's degree

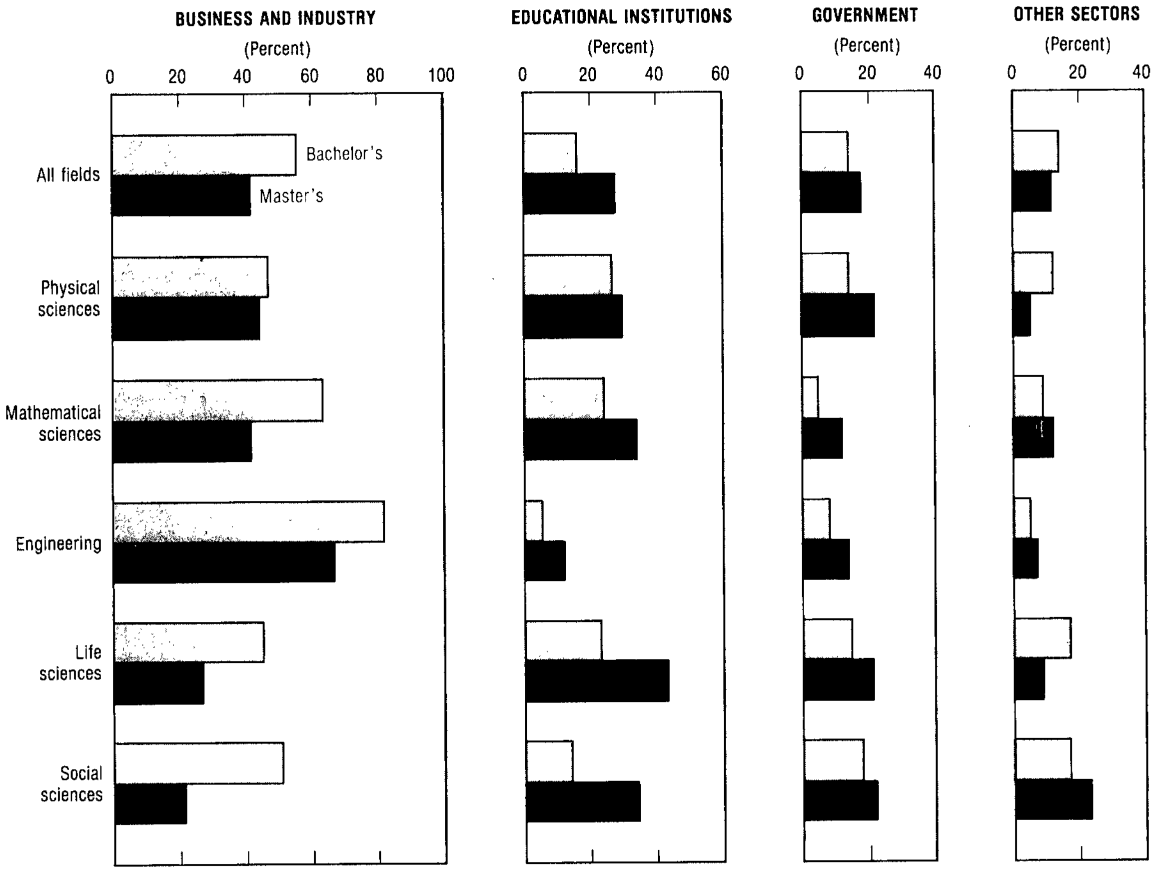
Figure 5-29
Unemployment rates of recent S/E graduates by race and degree level



[1]Data include both 1974 and 1975 graduates.
[2]Data include 1976 and 1977 graduates, based on a pooling of the 1978 and 1979 survey data.
REFERENCE: Appendix table 5-45.

Science Indicators—1980

Figure 5-30
Distribution of employed 1977 S/E graduates by field of degree and employment sector: 1979



REFERENCES: Appendix tables 5-47 and 5-48.

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graduates rose from 1.6 percent to 2.9 percent over the same period. Black S/E graduates have been highly concentrated in the social sciences and psychology, which accounted for about 65 percent of the bachelor's degrees awarded to blacks in 1978-79, compared to about 45 percent of the white S/E graduates.

The relatively small number of black graduates—and their correspondingly small representation in the sample surveys of recent graduates—has precluded a detailed analysis of their unemployment/underemployment trends by S/E field. Figure 5-29, however, does present separate statistics on unemployment rates for recent black and white graduates in all S/E fields for the combined graduation cohorts of 1974-75 (surveyed in 1976) and 1976-77 (surveyed in 1978 and 1979). These pooled data, although still subject to sizeable sampling error, highlight a significant unemployment problem among recent black S/E graduates, particularly in the social sciences, where their reported unemployment rate averaged 12.6 percent or 2.7 times that of white graduates.

Employment Sector

Since the employment experiences of new S/E graduates provide signals on shifts in both supply and demand, it is instructive to examine the employing sectors and work activities of recent graduates. Information on the employing sector and work activities of recent graduates provide insights into possible shifts in demand among the various sectors and work activities. Changes in demand among sectors, in turn, influence demand for scientists and engineers in various fields since some fields of employment are more dominant in one sector than in others.

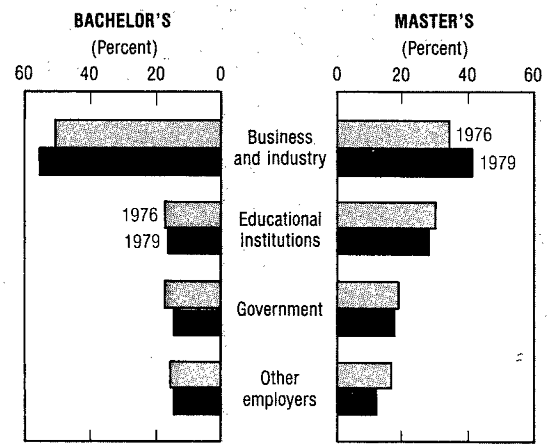
Employment affiliation varies widely by degree field. An indication of the early career relationship between degree field (as well as degree level) and employment sector can be obtained from the employment experiences of recent S/E degree recipients presented in figure 5-30. While 56 percent of those earning bachelor's degrees found employment in business and industry, over 80 percent of those with bachelor's degrees in engineering found jobs in industry.

The acquisition of a master's degree was accompanied by a relative decrease in the likelihood of industrial employment. Overall, industrial employment declined from 56 percent to 42 percent, for bachelor's and master's degree holders, respectively. This decline, which took place in all broad fields, was smallest among physical science and engineering degree holders; only among master's recipients in the latter field were more than one-half industrially employed 2 years following graduation.

The sectoral shift associated with the employment of recent S/E master's degree recipients was evident in educational institutions and government organizations. Thus, a greater proportion of master's degree holders found employment in these sectors than did baccalaureate holders in all broad fields examined.

Figure 5-31

Distribution of employed S/E degree recipients by sector of employment and degree level two years after graduation[1]



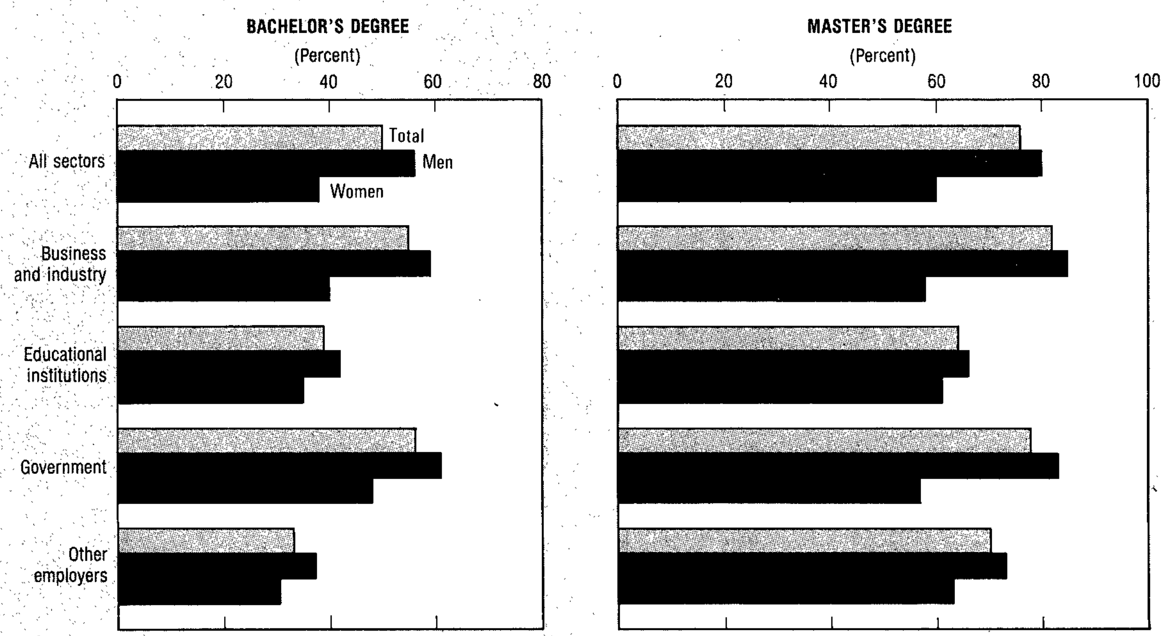
[1]Graduates from 1974/75 were studied in 1976 while 1977 graduates were studied in 1979.

REFERENCES: Appendix tables 5-47 and 5-48 and unpublished data.

Science Indicators—1980

Figure 5-32

Proportion of 1977 S/E graduates[1] employed in S/E jobs by degree level, sector of employment and sex: 1979



[1]Does not include those who were full-time graduate students in 1979.

SOURCE: National Science Foundation, *Employment Attributes of Recent Science and Engineering Graduates* (NSF 80-325).

Science Indicators—1980

Among recent graduates, there was a relative increase in industrial employment during the 1976-79 time period at both the bachelor's and master's level (see figure 5-31). This increase was offset by small declines in each of the other sectors. The decline in academic employment, although modest,[46] is expected to continue as demand for new S/E positions is reduced as a consequence of projected declines in academic employment opportunities.[47] The parallel shift toward industrial employment and away from academic employment among doctoral S/E's was noted earlier.

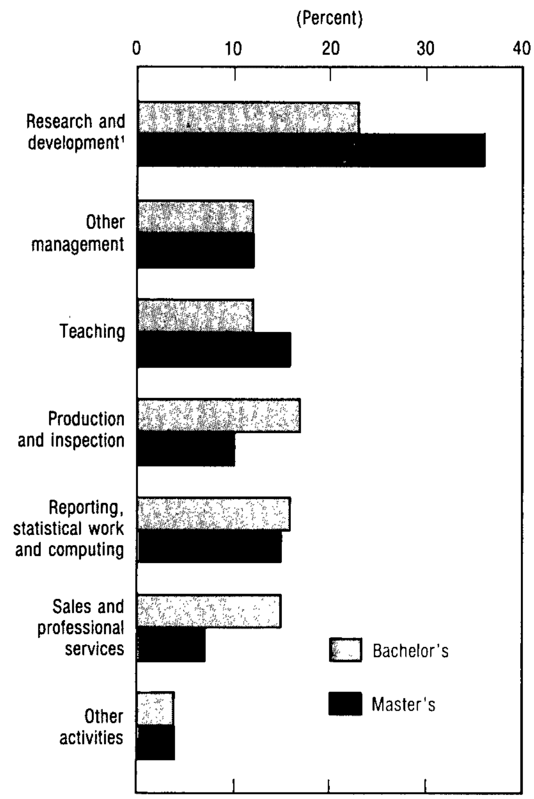
Given the sectoral differences in employment of recent graduates, the question arises as to their implications for employment in S/E-related jobs. S/E employment rates (proportion of S/E graduates employed in science and engineering jobs) in business and industry and in government were substantially higher than in other employment settings at both the bachelor's and master's levels (see figure 5-32). The higher S/E employment rate associated with the acquisition of a master's degree is evident in all employment sectors, although the bachelor's/master's differential varies to some extent. This differential (irrespective of sex) is lowest in the academic sector where the S/E employment rate for master's degree holders is about 27 percent higher than for baccalaureate holders. In comparison, the data show an analogous differential of about 40 percent in government organizations, 50 percent within business and industry, and more than 100 percent among other (combined) employers.

Primary Work Activity

An important aspect of the state of the S/E enterprise is the extent to which scientists and engineers are engaged in research and development activities. Involvement in R&D activities, however, varies considerably by degree levels (see figure 5-33). Two years after graduation, only about 23 percent of baccalaureate holders were involved in R&D, and an additional 12 percent were primarily involved in teaching.

Figure 5-33

Distribution of 1977 S/E graduates by field of degree and primary work activity: 1979



[1]Includes management of R&D.

REFERENCES: Appendix tables 5-47 and 5-48.

Science Indicators—1980

A study of bachelor's degree holders reveals a change in the pattern of work activities characterized by an increase in R&D and teaching activities accompanied by a decline in production/inspection and sales/professional services. Other work activities showed little change.

The increase in R&D and teaching activities associated with the acquisition of advanced education has been noted elsewhere,[48] and is most evident at the doctoral level.

[46]This aspect of employment is especially sensitive to the treatment of full-time graduate students who are included in this analysis. If they are *excluded* from consideration, the decline in academic employment is much more pronounced; i.e., from 12 percent to 9 percent for baccalaureate holders and from 24 percent to 20 percent for master's degree recipients.

[47]*Research Excellence Through the Year 2000: The Importance of Maintaining a Flow of New Faculty into Academic Research* (Washington, D.C.: National Academy of Sciences, 1979).

[48]"Employment Characteristics of Recent Science and Engineering Graduates: The Effects of Work Experience, Advanced Degrees, and Business Cycles," *Reviews of Data on Science Resources*, No. 36, National Science Foundation, (NSF 80-311).

Chapter 6
Public Attitudes Toward Science and Technology

Public Attitudes Toward Science and Technology

INDICATOR HIGHLIGHTS

- The public's overall view of science and technology is strongly favorable. Seventy percent of the American public believe that the benefits from scientific research outweigh the harms. Americans attribute U.S. prestige and influence largely to technological and industrial know-how and, to a lesser extent, to scientific creativity. The public has expressed high regard for science and technology in surveys since 1957, although it was higher in 1957. (See pp. 160-161, 163.)
- However, a significant portion of the U.S. public views negatively some aspects of the social impact of science. Among the concerns is that scientific discoveries are changing our lives too fast (53 percent) and that they tend to break down people's ideas of right and wrong (37 percent). These unfavorable responses became more prevalent between the late 1950's and the mid-1960's, but apparently have not increased since then. (See pp. 162-163.)
- Throughout the 1970's, the public has ranked the improvement of health care first on a list of areas that should receive science and technology funding from tax money. In 1979, the public placed health care first, followed closely by the development of energy sources and education. The improvement of education and of defense weapons are two areas that have risen on the list since 1972. (See pp. 166-168.)
- Although at times large segments of the public are aware of and interested in particular science and technology issues, only about 18 percent of the adult population in the United States are regularly attentive to science and technology. The attentive public is that segment of the population interested in and knowledgeable about science and technology, which keeps informed about these fields. A high level of education is the strongest predictor of attentiveness; politically active persons, males, and young people are also more likely to belong to this group. By comparison, only 8 percent of the population over 21 were attentive to science and technology in 1957. (See pp. 160, 176-178.)
- The public is unequivocal in recognizing the expertise of scientists and engineers on problems relating to their areas of specialization. They are placed highest among eight groups who might make public policy decisions about space exploration, chemical food additives, and nuclear power. Federal specialized and regulatory agencies rank next highest in public confidence, except over the issue of locating a nuclear power plant. On that issue, scientists and engineers are considered first in competency, citizens of the affected community second, and a Federal regulatory agency or commission third. (See pp. 175-176.)
- Forty-three to 57 percent of the public, and 59 to 81 percent of the attentive public, think it is very likely that researchers will come up with more efficient sources of cheap energy, the ability to anticipate earthquakes, a cure for common forms of cancer, and a way to desalinate seawater within the next 25 years. The public is less sanguine about the prospect of putting communities in outer space (only 17 percent think this is very likely) or effectively reducing the crime rate through research (14 percent). Attentives are equally skeptical that research can reduce the crime rate, but they have higher expectations than nonattentives in the other cases. Young people, those with less than a high-school education, and women have especially few expectations. The highly educated expect more of these accomplishments than does the average person. (See p. 165.)
- Only in one out of the five areas of research presented in the survey is there a significant opposition to scientific study. As many as 65 percent of the total public and 49 percent of attentives believe that scientists should not study ways of creating new forms of life. (See pp. 165-166.)
- While space exploration has fairly low priority for science and technology tax funds in comparison with other possible areas, 60 percent of the total public and 87 percent of the attentive public still favor it. More of the public sees benefits than sees harms stemming from space exploration; this is especially so for the attentives. (See pp. 169-170.)
- More than 70 percent of the adult population

state that they would make special efforts to avoid foods containing artificial additives if a group of scientists were to report that the additives cause cancer. About half of the public also claim to have changed their shopping or eating habits for such reasons. More people see harms in food additives than benefits, with cancer and other diseases being reported as the greatest perceived dangers. On the other hand, many see benefits in additives related to the retardation of spoilage. (See pp. 170-171.)

- The controversies surrounding nuclear power plants are known to 91 percent of the population. While 63 percent of those who have heard of the controversies see benefits from the production of nuclear energy, 78 percent see harms. Of the total public, 62 percent oppose the location of a nuclear power plant in their area. The main fears are the possibility of a meltdown or nuclear explosion, and of low-level radiation leaks. However, the public does not support the general abandonment of nuclear power. Attentives support nuclear power more than nonattentives do. (See pp. 171-173.)
- About 10 percent of the public feel that they are very well informed about new scientific discoveries and new technologies; on nine different issues involving public affairs, an average of only 14 percent of the public consider themselves very well informed. Almost 60 percent of those who say they would not take an active part in a nuclear power plant controversy give insufficient information as one reason, and almost 70 percent of those who would not take an active part in a controversy on outer space give the same reason. (See pp. 173-175, 176.)

In a pluralistic, participatory political system like that of the United States, it is appropriate to examine the attitudes of the public toward science, technology, and related public policy issues. It is recognized at the outset that most Americans do not have firm opinions about science and technology and that a significant portion of the general public has little scientific information or training on which to base evaluations of scientific and technological issues. Nonetheless, the public always retains a veto on all political questions if it becomes motivated to utilize that power.

Not only is it important for the public to understand the role and contributions of science and technology, but science and technology decision-makers also should understand the attitudes of the public. "The scientific community," Kenneth Boulding has suggested, "should be deeply concerned about the images of science that lie outside it and even those that lie within it, for the probability of adverse changes in these images is at least large enough so that ignorance about them would be unwise."[1] Boulding continues that "it is entirely consistent with the ethics of the scientific community to try to dispel illusions about it...."

Hence, it is appropriate to examine the attitudes of the public toward science and technology and to use opinion polling for this purpose. Polls, like all methods of measuring public views of social issues, have strengths and weaknesses.[2] Among their strengths is that through the use of scientific sampling methods they can reach a truly representative sample of the population and aggregate the feelings of those who are inarticulate as well as those who express their feelings in a variety of forums. Poll results are highly dependent upon the wording of questions, and it is at this point that they are most vulnerable to misuse. Only by examining a wide range of questions, by using questions that employ trade-offs, and by comparing answers to the same question over time to ascertain trends, can a valid overall picture of public views be developed. The questions chosen for this purpose are based on assumptions about what the public may believe. These beliefs are not necessarily shared by scientists and engineers themselves.

The survey on which the bulk of the present chapter is based involved 1,635 interviews with a national probability sample of the adult, noninstitutionalized population, 18 years old and over, in the 48 contiguous States. Questions were written to minimize bias and to be comparable both with earlier surveys conducted for the National Science Board and with surveying conducted in the late 1950's, near the time of Sputnik. The interviews

[1] Kenneth E. Boulding, "Science: Our Common Heritage," *Science*, vol. 207 (February 22, 1980), p. 833.

[2] The possibilities and problems of public opinion surveying are discussed in Donald P. Warwick and Charles A. Lininger, *The Sample Survey: Theory and Practice* (New York: McGraw-Hill, 1975).

were carried out between October and December 1979.[3]

Recent studies have shown that there is an important segment of the population that not only has a great interest in, but also has considerable knowledge of, any field of public concern, such as science and technology. The rest of the public normally take only occasional interest in the subject, mostly when it affects or threatens to affect their daily lives. They are less informed about the field, and their views, when expressed, are less likely to remain stable.[4]

A political scientist has referred to the minority of the population that actively concerns itself with foreign policy issues as the "attentive public" for foreign policy.[5] Presumably, attentive publics exist in all areas of public concern. Of course, different issues engage the attention of different people, and there are times when political referenda and the like force the mass public to acquire some information about a current issue. Attentives, however, remain cognizant of a subject over long periods of time.

There is no direct method for measuring attentiveness, but an index can be devised based on one or more criteria. For purposes of the present report, individuals were classified as attentive to science and technology[6] if they scored high on three different measures. The first measure was of level of interest in science and technology. The second component of attentiveness was level of knowledge about science and technology, while the third component was the extent to which persons regularly availed themselves of scientific and technological information.[7]

The survey found that about one in five members of the public is interested in, is informed about, and keeps up on science and technology (see table 6-16). Yet the rest of of the public also has opinions about the benefits or harms that may be derived from science and technology. People also express views on the contributions of science and technology to U.S. influence in the world, as well as what areas scientists should and should not study, what research can achieve in the opinion of the public, and what priorities should be set when it comes to supporting scientific and technological activities with tax money. Those subjects will be dealt with in this chapter. A section will also be devoted to public attitudes toward three highly visible issues: space exploration, the use of food additives, and the building of nuclear power plants. These issue areas served to focus the public's general attitudes about science and technology on a few specific cases. Such cases may produce answers that are more firmly rooted in factual information than the general attitudes are, and consequently are less fragile. Finally, a section will discuss how informed the public considers itself and what groups it considers best qualified to make policy decisions that affect science and technology.

GENERAL ATTITUDES TOWARD SCIENCE AND TECHNOLOGY

General Benefits and Risks

The public's view of science in general can influence its reaction to specific science-related issues. If it has serious doubts about science, it may also be inclined to distrust scientists. When public issues arise that have a scientific aspect, public acceptance of scientists' participation in the controversy may depend on the public's general attitudes toward science.[8]

How, then, does the public view scientific research in general? Its overall reaction is very favorable. Seven in 10 adults view scientific research as

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[3]With this size of sample, the error of the percentages reported should be 4 percentage points or less, although for subsamples such as the group with a college degree, the error may be higher. For survey data, method, and confidence intervals, see Koray Tanfer et al., *National Survey of the Attitudes of the U.S. Public Toward Science and Technology*: Final Report (Philadelphia: Institute for Survey Research, Temple University, 1980). The design of the questionnaire is explained in Jon D. Miller and Kenneth Prewitt, *The Measurement of the Attitudes of the U.S. Public Toward Organized Science* (Chicago: National Opinion Research Center, University of Chicago, January 1979). The analytic report for the entire project is Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U.S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, July 1980). These reports, which were prepared specifically for the present chapter, can be obtained from the National Technical Information Service, along with the related data tapes.

[4]Ibid., pp. 14-17.

[5]Gabriel A. Almond, *The American People and Foreign Policy* (New York: Harcourt, Brace and Co., 1950).

[6]An attempt was made to distinguish attentiveness to science from attentiveness to technology. The present survey, with the U.S. adult population, found that in general the same people are attentive to both. However, a separate study found some difference in attentiveness to science and to technology among younger students. (See figure 6-2.)

[7]Further information about the attentive public and its development is given later in this chapter.

[8]Many of the questions discussed in this chapter do not distinguish between science and technology. Although a specific effort was made to bring out this difference in the responses to the survey, it appeared in only a few responses. See Miller, Prewitt, and Pearson, pp. 61-66. An earlier study, performed with the California population, reported that the public makes this distinction. See Todd La Porte and Daniel Metlay, *They Watch and Wonder: Public Attitudes Toward Advanced Technology* (Berkeley, Calif.: Institute of Governmental Studies, University of California, Berkeley, 1975).

leading to more benefits than harms (table 6-1).[9] Only 1 in 10 thinks that research has more harmful than beneficial consequences. In looking at the various questions that over the years have asked respondents to balance the overall benefits against the overall harms, it is evident that the proportion of people who feel that science or science and technology produce more benefits than harms has been and continues to be high (table 6-2; also, appendix table 6-1). However, public optimism about science and technology clearly declined from 1957 to 1980.

[9]On the tables, N represents the sample size, i.e., the number who were asked a given question.

Table 6-1. Beneficial versus harmful consequences of scientific research: 1979

Response	Percent
Benefits have outweighed harms	70
Harms have outweighed benefits	11
About equal	13[1]
Don't know	6
	(N = 1,635)

[1]Only "benefits have outweighed harms" and "harms have outweighed benefits" were offered as choices. However, 13 percent volunteered "about equal."

REFERENCE: Appendix table 6-2.

Science Indicators—1980

Table 6-2. Questions comparing overall benefits and harms from science and technology: 1957-1980

Questions	Percent of responses that were favorable
All things considered, would you say that the world is better off or worse off because of science? (1957; N = 1,919)	88
Do you feel that science and technology have changed life for the better or for the worse? (1972a; N = 2,209)	70
Most scientific discoveries have done me more personal good than harm. (1972b; N = 1,548)	78
Do you feel that science and technology have changed life for the better or for the worse? (1974; N = 2,074)	75
Do you feel that science and technology have changed life for the better or for the worse? (1976; N = 2,108)	71
Future scientific resarch is more likely to cause problems than to find solutions to our problems. (1979; N = 1,635)	60
In your opinion, over the next 20 years will the benefits to society resulting from continued technological and scientific innovation outweigh the related risks to society, or not? (1980; N = 1,487)	58

NOTE: The number of choices given to respondents when they were asked these questions varied. Thus, the 1957 survey offered five choices and combined the two positive responses, "The world is better off because of science" and "The world is better off, qualified." The 1972a, 1974, and 1976 surveys gave two choices, "better" or "worse"; although "both" and "neither" were volunteered by some respondents, only the response "better" is included here. The 1979 survey had four choices ("strongly agree," "agree," "disagree," and "strongly disagree") and the two positive responses were combined. The 1980 survey offered only "yes" or "no;" although "it depends" was accepted if volunteered by the respondent, the above percentage only includes the "yes" responses.

SOURCES: 1957: *The Public Impact of Science in the Mass Media* (Ann Arbor, Mich,: Survey Research Center, University of Michigan, for National Association of Science Writers, 1958), p. 179.

1972a, 1974, 1976: *Attitudes of the U. S. Public Toward Science and Technology* (Princeton, N.J.: Opinion Research Corporation, 1976), p. 18.

1972b: The Harris Survey, Release of February 17, 1972.

1979: Koray Tanfer, Eugene Ericksen, and Lee Robeson, *National Survey of the Attitudes of the U. S. Public toward Science and Technology,* Volume II: Detailed Findings (Philadelphia: Institute for Survey Research, Temple University, 1980), p. 96. Similar results were obtained with the same question in early 1980 in *National Environmental Survey Final Results* (Washington: Resources for the Future, for President's Council on Environmental Quality, 1980), p. 10a.

1980: *Risk in a Complex Society* (Marsh & McLennon Companies, Inc., 1980), p. 12.

Science Indicators—1980

The tendency to say that the benefits strongly outweigh the harms from science clearly increases with education, and a larger proportion of males than females, and attentives than nonattentives, feel that this is so. It also appears that at both ends of the age spectrum—those under 25 and those over 64—there is somewhat less inclination than at the intermediate ages to credit science strongly with providing more benefits than harms (see appendix table 6-2).

This positive view of the benefits of scientific investigation appears to be just as prevalent in the rest of the Western World. In 1977, only about 5 percent of the population of any one of nine Western European countries felt that science produces more disadvantages than advantages.[10] A large majority (69 percent) agreed with the statement: "It is one of the most important factors in the improvement of our daily life."

On the other hand, there are some Americans who see drawbacks to science, especially when it comes to its impact on our values and way of life. As many as 37 percent of the population in the United States agree with the statement that "scientific discoveries tend to break down people's ideas of right and wrong."[11] In 1957, 23 percent of adults shared this view.[12] Also, 53 percent of the public think that "scientific discoveries make our lives change too fast," as against 44 percent who think otherwise (appendix table 6-3). When similar questions were asked in the 1960's, they produced about the same percentages of unfavorable responses; however, they elicited fewer unfavorable responses in the late 1950's. It must be recognized, therefore, that between a third and a half of the public sees a negative side to the contributions of science, and that this portion has increased since 1957.[13]

Some concerns about science also prevail in nine Western European countries, where 57 percent of the population agree that nowadays some scientific discoveries are put into practice before future con-

[10] *Science and European Public Opinion* (Brussels: Commission of the European Communities, 1977), p. 36. The two surveys sponsored by the Commission are discussed in Max Kaase, "Fear of Science Versus Trust in Science: Future Trends," in Andrei S. Markovits and Karl W. Deutsch, eds., *Fear of Science, Trust in Science* (Cambridge, Mass.: Oelgeschlager, Gunn, and Hain, Publishers, Inc., 1980), pp. 177-198.

[11] Tanfer et al., p. 126.

[12] See National Association of Science Writers, *The Public Impact of Science in the Mass Media* (Ann Arbor: Survey Research Center, University of Michigan, 1958), p. 186.

[13] In another series of surveys in 1972, 1974, and 1976, fewer than one in four members of the American public felt that science and technology changed things too fast. Unlike some of the other studies discussed, however, these provided three possible responses rather than two and included technology in addition to science. See *Attitudes of the U.S. Public Toward Science and Technology*. Study III (Princeton, N.J.: Opinion Research Corporation, 1976), p. 17. Negative reactions to science and scientists from as much as three-fourths of the population are reported in *The Harris Survey*, Releases of February 17, 1972 and February 27, 1978. However, there were higher levels of favorable response to other science-related questions.

Table 6-3. Attitudes of attentives and nonattentives toward the benefits of science

	Percent			
	Attentives		Nonattentives	
	1957	1979	1957	1979
On balance, the benefits of scientific research have outweighed the harmful results	96	90	87	66
Scientific discoveries make our lives change too fast	27	43	44	58
Scientific discoveries tend to break down people's ideas of right and wrong	11	27	24	42
Scientific discoveries are making our lives healthier, easier, and more comfortable	100	90	96	83
	(N = 146)	(N = 274)	(N = 1,773)	(N = 1,198)

NOTE: The 1957 study was based on adults who were 21 years old and over, while the 1979 sample included 18-year-olds and over. Percentages were, therefore, recalculated to exclude the 18- to 20-year-olds in the 1979 sample. The question wording was not exactly the same in 1957 and 1979, but was similar enough to allow comparisons to be made.

SOURCE: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U. S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), p. 134.

Science Indicators—1980

sequences have been sufficiently studied. Moreover, 67 percent believe that scientific and technical development is sometimes accompanied by increasingly large risks that will be difficult to overcome. However, 69 percent believe that scientific knowledge is good in itself and it is only the way it is put into practice that often creates problems.[14]

In the United States, the proportion expressing concern about the tendency of scientific discoveries to break down people's ideas of right and wrong is relatively high among blacks (54 percent). It is also high among those with less than a high-school diploma (46 percent). It is low among those with college degrees (23 percent). Similarly, blacks tend, on the average, to feel that scientific discoveries make our lives change too fast (about 63 percent) as do those of all races with less than a high-school diploma; persons with high levels of education or income are less likely to feel that way.[15]

In summary, compared with two decades ago, public perception of the benefits of science has eroded somewhat but remains strong.[16] At the same time, concern about potential risks associated with science has grown. The attentive public is much more likely to view scientific investigation as beneficial than is the rest of the population (table 6-3). While 90 percent of attentives believe that the benefits of science outweigh its harms, this view is shared by only 66 percent of the nonattentive public. Again, only 4 percent of the attentives, but 12 percent of nonattentives, feel that the harms are greater than the benefits.[17] While attentives are so supportive of science, the proportion of attentives who feel that the benefits of science outweigh its harms may have declined slightly since 1957. On the questions critical of science, regarding breaking down ideas of right and wrong and changing life too fast, attentives are clearly less negative than the rest of the public. However, both attentives and nonattentives have grown more critical since 1957.

[14] *The European Public's Attitudes to Scientific and Technical Development* (Brussels: Commission of the European Communities, 1979), pp. 20-23. The European public is similarly sensitive to the possible penetration of science into the inner sphere of personal values. See Kaase, p. 185.

[15] Tanfer et al., pp. 124, 126.

[16] Similar concerns are expressed about technology. In early 1980, 59 percent of a national sample agreed that people would be better off if they lived a more simple life without so much technology. Still, 81 percent agreed that technology will find a way of solving the problem of shortages and natural resources. See Resources for the Future, *National Environmental Survey, Final Results* (Washington: President's Council on Environmental Quality, 1980), p. 10a.

[17] Jon D. Miller, Kenneth Prewitt, and Robert Pearson, unpublished tabulations. These percentages apply to the population over 18, though text table 6-3 is limited to those 21 and over.

Contribution to U.S. Influence

A further measure of the standing that science and technology have in the United States, and the confidence that the public has in them, is the extent to which the public believes they have contributed to U.S. influence. When given a chance to select two factors out of eight possibilities, respondents cited technological know-how more often than anything else as contributing the most to U.S. influence in the world (table 6-4). Scientific creativity was fourth on the list.[18] Americans also show their pride in the Nation's scientific creativity in another way. When asked to identify the two factors that contribute the *least* to the degree of influence the United States has in the world, technological know-how and scientific creativity are mentioned least often (see appendix table 6-4).

Similar results were found in earlier surveys. When people were asked to rate a set of factors as to whether they will be major or minor contributors

[18] By a small margin, the U.S. economic system is listed more often than technology as the *first* choice (appendix table 6-4), but the combined effect of the two choices is as shown in table 6-4.

Table 6-4. Proportion of public who perceive selected factors as contributing to U. S. influence in the world: 1979

Contribute most	Percent[1]
Our technological know-how	46
Our form of government	41
Our economic system	27
Our scientific creativity	22
Our natural resources	19
Our religious heritage	15
Our educational system	14
The racial and ethnic mixture of our population	11
Our technological know-how	8
	(N = 1,635)
Contribute least	**Percent[1]**
Our religious heritage	49
The racial and ethnic mixture of our population	47
Our educational system	25
Our natural resources	19
Our economic system	12
Our form of government	12
Our scientific creativity	9
Our technological know-how	8
	(N = 1,635)

[1] Percentages add to more than 100 because the respondents were asked to name two factors under each heading.

REFERENCE: Appendix table 6-4.

Science Indicators—1980

Table 6-5. Public's identification of major factors that will make America great

Factor[1]	Percent 1973	1975	1977	1979
Scientific research	NA	NA	91	89
Industrial know-how	87[2]	86[2]	80	80
Rich natural resources	65	79	77	79
Democracy as its political system	NA	NA	72	74
Skill at organizing production	NA	NA	71	74
Technological genius	NA	NA	78	73
Free, unlimited education for all qualified	78	75	75	67
Deep religious beliefs	NA	NA	61	57
People of different racial and religious backgrounds	57	58	NA	NA
	(N = 1,513)	(N = 1,519)	(N = 1,498)	(N = 1,514)

[1]Factors chosen as making a major contribution to America's greatness in the next 10 years (1973 and 1975) and in the next 25 (1977 and 1979), selected from a longer list so as to be comparable to the factors on table 6-4. Multiple responses were accepted.
[2]Wording in 1973 and 1975 was "Industrial know-how and scientific progress."

NA = Not available.

REFERENCE: Appendix table 6-5. Science Indicators — 1980

Table 6-6. Proportion expecting scientific and technological achievements in 25 years: 1979

Achievement	Percent who believe achievements are: Very likely	Possible	Not likely	Sample size
More efficient sources of cheap energy				
Total public	57	34	7	1,635
Attentives	81	16	3	301
A way to predict when and where earthquakes will occur				
Total public	52	38	8	1,635
Attentives	74	24	2	301
A cure for the common forms of cancer				
Total public	46	44	8	1,635
Attentives	59	33	7	301
A way to economically desalinate sea water for human consumption				
Total public	43	42	10	1,635
Attentives	63	34	4	301
A way to put communities of people in outer space				
Total public	17	38	42	1,635
Attentives	28	42	29	301
New ways of effectively reducing the crime rate				
Total public	14	41	42	1,635
Attentives	14	41	44	301

REFERENCE: Appendix table 6-6. Science Indicators — 1980

to America's future greatness, scientific research was picked by 9 of every 10 individuals as making a major contribution (table 6-5). Scientific research and industrial know-how have been at or near the top of the list since the question was first asked in 1973.[19] However, technological genius has ranked slightly lower.

The foregoing results suggest that Americans have a high regard for the contributions of science and technology to their comfort, welfare, and international prestige, perhaps with a higher regard for science than for technology. And while the benefits of science and technology are appreciated by varying proportions of the public at different times, and belief in the benefits of science dropped in public support from 1957 to 1979, the ratings generally have remained high.

PUBLIC PREFERENCES AND EXPECTATIONS

Expected Advances

While the American public has a high regard for science and technology, it also has views about what they can and cannot accomplish and what should be given priority for investigation. Areas of concern include health problems, such as finding a cure for cancer; economic problems, such as developing more efficient sources of cheap energy; and problems due to natural disasters, such as predicting when and where earthquakes will occur. More than half of the public believe it is very likely that researchers will find solutions to the latter two problems within the next 25 years (table 6-6); almost half think that a cure for the common forms of cancer will also be found, and a similar proportion believe that an economical way to desalinate seawater for human consumption will be invented. About 9 out of 10 consider it possible or very likely that these problems regarding energy, earthquakes, and cancer will be resolved within 25 years. There are some people who believe that the U.S. public has been oversold on science and that, as a result of subsequent disappointments, support for science has dropped.[20] In the case of problems like health, energy, seawater desalination, and earthquake prediction, at least, this does not seem to be true. However, when the issue is putting communities of people in outer space or reducing crime, considerably fewer believe that science and technology can accomplish these things.

Other studies have also found that a majority (55 percent) of Americans expect a cure for cancer to be found in their lifetime.[21] However, similar majorities do not expect a cure for heart disease or stroke. Majorities from 55 to 74 percent believe that science will not succeed in finding ways to predict and prevent serious damage from floods, earthquakes, hurricanes, and cyclones. The pessimism in this case may be related to the small possibility of preventing damage from these disasters, in addition to predicting them.

Men are more optimistic than women about the possible achievements listed in table 6-6. If a scale is constructed based on how many of the six achievements a respondent considers very likely, almost a third of the male respondents had a score from four to six (appendix table 6-7). Among women, only 23 percent shared these high expectations. Close to a third of the respondents with less than a high-school education think that none of the achievements is very likely, a significantly greater proportion than is found among those with more education. At the other end of the educational spectrum, those with a graduate degree are much more inclined than others to expect four or more of the listed achievements from research.

The attentive public is more sanguine about the possibility of putting communities of people in outer space and about the four biological and physical problem areas than is the rest of the public, but is as skeptical as the rest of the public about the ability of researchers to reduce the crime rate (see table 6-6 and appendix table 6-6). Overall, attentives score much higher than nonattentives in the number of achievements that they expect in 25 years (appendix table 6-7).

Limiting Scientific Inquiry

In recent years, the question of the "limits of scientific inquiry" has aroused much controversy

[19] In the *Science Indicators* survey, people were asked to pick two from a limited list of factors as contributing the most to U.S. influence in the world. In the Harris surveys, they were asked to examine a larger set of national attributes and to state whether each is a major or minor contributor to America's greatness. Whereas the *Science Indicators* study permits only 2 of 8 characteristics to be picked, all 20 to 23 attributes could be rated as major in the Harris poll.

[20] See the speech by Presidential Science Adviser, Frank Press, at a meeting of the American Association for the Advancement of Science, June 19, 1980. Also see Anna J. Harrison, "Science, Technology, and Public Benefits," in *National Science and Technology Policy Issues, 1979*, Part I, *A Compendium of Papers*, Committee Report of the Committee on Science and Technology, U.S. House of Representatives, April 1979, p. 40.

[21] ABC News-Harris Survey, Release of May 28, 1979.

Table 6-7. Proportion of attentives and of total public opposing selected areas of scientific inquiry: 1979

Scientists should not conduct studies for—	Percent of Attentives	Percent of Total public
Creating new forms of life	49	65
Discovering intelligent beings in outer space	10	36
Extending life span to 100 or more	19	29
Precise weather control and modification	20	28
Detecting criminal tendencies in very young children	13	16
	(N = 301)	(N = 1,635)

REFERENCE: Appendix table 6-8.

Science Indicators — 1980

among scientists.[22] In past centuries, interference with scientific inquiry generally has stemmed from the possibility that scientific conclusions might conflict with the teachings of established authorities. Today there is new interest in limiting inquiry because of the possibility that scientists and engineers may accidentally and irreversibly unfetter a natural force or a technology that will adversely change the world as we know it.

The majority of Americans apparently do not wish to limit scientific inquiry. Among the five subjects offered for their consideration in the present survey, a majority is opposed only to studies that might allow scientists to create new forms of life (table 6-7). Almost two-thirds of the public believe that studies in this area should not be pursued. Fear of the unknown and of possible misuse of the discoveries by some malevolent dictator are among the reasons that could be given for opposition to such "genetic engineering."[23] Close to a third of the American public also are cautious about three of the other areas mentioned, holding that they should not be studied (see table 6-6). On the other hand, more than 8 in 10 members of the public think that detecting criminal tendencies in very young children is a subject that scientists should study.

Members of the attentive public are less inclined to restrict scientific study than are nonattentives, regardless of the topic. The differences are considerable, except in regard to the study of methods to detect criminal tendencies in very young children, which both strongly support. Like the public as a whole, attentives are more willing to restrict research on the creation of new life forms than anything else. No more than 10 to 20 percent of the attentives would restrict research in any of the other fields.

Europeans, too, show concern about genetic research. In nine Western European countries in 1978, 35 percent of the respondents opposed genetic experiments because they involved unacceptable risks, compared to 33 percent who thought they were worthwhile (appendix table 6-9). On a country-by-country basis, however, only the Danes, Germans, and Dutch showed strong opposition. People in France and Britain were less strongly opposed, while people in Italy, Ireland, Belgium, and Luxembourg actually favored such research more than they opposed it.

Use of Tax Funds for Science and Technology

About half of the funding for research and development comes from Federal sources.[24] Because the taxpayers pay these bills, their views on spending priorities for science and technology are important. Public preferences also reflect current social concerns, hopes, fears, and public expectations from science and technology.

Preferences for the support of various scientific and technological areas have not changed much in recent years. More taxpayers would like to see their taxes spent on health-related problems than on anything else, and improving health care has been the first choice of Americans among 12 or 14 items, at least during the 1970's (table 6-8 and appendix table 6-10). Developing energy sources and conserving energy ranked second for tax support in

[22] See special issue of *Daedalus*, vol. 107 (spring 1978), devoted to this topic.

[23] Ibid., pp. 214-215.

[24] See chapter of this report entitled Resources for R&D.

Table 6-8. Areas the public would most like to receive science and technology funding from tax money: 1979

Area	Attentives		Total public	
	Percent	Rank	Percent	Rank
Improving health care	47	2	50	1
Developing energy sources and conserving energy	61	1	46	2
Improving education	34	3	39	3
Reducing crime	19	6	36	4
Developing or improving methods for producing food	24	5	23	5
Reducing and controlling pollution	26	4	22	6
Developing or improving weapons for national defense	18	7	16	7[1]
Preventing and treating drug addiction	9	11[1]	16	7[1]
Developing faster and safer public transportation within and between cities	14	9[1]	13	9
Improving the safety of automobiles	5	13	9	10
Finding better birth control methods	9	11[1]	9	11
Discovering new basic knowledge about man and nature	15	8	8	12
Exploring outer space	14	9[1]	6	13
Predicting and controlling the weather	4	14	4	14
	(N = 301)		(N = 1,635)	

[1]Tied for the indicated rank.

NOTE: Percentages add to more than 100 because respondents were asked to name three areas.
SOURCES: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U.S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), p. 137; Jon D. Miller, unpublished data.

Science Indicators—1980

1979, although no prior benchmark is available against which to check this preference. A growing preoccupation of the American public during the 1970's has been education. The high ranking given to science and technology expenditures for reducing crime is surprising in view of the fact that achievements in this area are not considered particularly likely (see table 6-6). This result, along with the fact that there is such a low level of willingness to restrict research to detect criminal tendencies in the young (see table 6-7), suggests a special public concern about crime.[25]

The rank of improving defense weapons also has risen dramatically from very low levels in 1972 and 1974. On the other hand, the issue of reducing pollution has been dropping somewhat in relative importance to the American public since 1972, as has improving the safety of automobiles. The consistently low ranks that exploration of space and search for new knowledge about man and nature have held suggest that the public's interest tends to focus on the practical and immediate rather than on results that are remote from daily life. However, when the public senses that a practical problem is fairly well under control, it quickly relegates it to a lower priority. Thus, finding better birth-control methods is now mentioned most often, along with the exploration of space, as an area where tax expenditures are *least* wanted (appendix table 6-11). In 1972, birth control was fourth on the list of areas related to science and technology that people least wanted to be funded from their taxes.

These results can be compared with the public's response to a similar list of spending priorities, this time with no reference to science and technology

[25]The relation of science and technology to the control of crime is discussed in National Science Foundation, *The Five-Year Outlook: Problems, Opportunities, and Constraints in Science and Technology*, Vol. II: *Source Materials*, 1980, pp. 607-638.

(appendix table 6-12).[26] Thus, during the decade of the seventies, a strong majority of the public have consistently felt that the United States is spending too little on attempting to halt the rising crime rate. This may help to explain the interest in spending science and technology funds in this area (table 6-6). A similar situation may hold with drug addiction. With regard to defense, the belief that the Government is spending too little in this area has risen, according to these studies, from 11 percent of respondents in 1973 to 56 percent in 1980; this result should be compared with the increased interest in science and technology funding for defense weapons (see appendix table 6-10). Health and education receive strong support for general funding, just as they do for science and technology funding. Space exploration rose in the 1970's as an area both for general and for science and technology funding, though it remains low in comparison with other areas.

Other evidence of the priority that the American public would place on health-related research exists. In a 1978 study,[27] 45 percent of a national sample placed cancer first and 14 percent placed it second among five problems that they would like to see scientific and technological research focus on solving. Energy ranked second, with 22 percent placing it first and 27 percent listing it as their second choice. Among young people in a 1976-77 study, 81 percent of 13-year-olds, 86 percent of 17-year-olds, and 94 percent of those between the ages of 26 and 35 would approve of giving money to scientists to find ways to cure a very rare disease.[28]

The Western European public, too, in 1977 placed medical and pharmaceutical research ahead of all other problems for which money should be made available for research.[29] Next in importance were meeting the world's food needs and controlling pollution. About half the adults in nine European countries were for reducing the amount of money allocated for space exploration, and 44 percent wanted to reduce funds for scientific research directed toward armaments and national defense. Almost a third believed the funding of research for weather forecasting and control and for public transportation should be reduced. In 1972 and 1980, French respondents were asked whether it would be desirable to increase funding for scientific research in various areas.[30] In both years, the areas were favored in the following order: health, the environment, consumer goods, civil atomic energy, aviation, military research, and space.[31] While support for these expenditures generally decreased from 1972 to 1980, opposition to funding military research dropped strongly. This result parallels the increase in support for defense-related science and technology funding in the United States, as reported in table 6-8.

The 1979 attentives supported the funding of methods to develop new energy sources and conserve energy ahead of all other activities in the area of science and technology (table 6-8). Health care came second. They also gave higher priority than did the total public to discovering new basic knowledge about man and nature and to exploring outer space. They placed reducing crime lower, as well as preventing and treating drug addiction and improving the safety of automobiles.

In sum, the American public wants research to advance in most of the areas asked and is optimistic that, within the next 25 years, many of the problems we face today will be solved. But Americans are concerned about genetic modification research, and some pessimism is expressed about the likely success of science in reducing crime. The proportion of the public willing to have its tax dollars earmarked for a specific scientific endeavor is an important index of public concern. It shows where science and technology are likely to have political support and, perhaps, where stronger efforts might be made to persuade the public of the goals of research. Clearly, there is strong support for the eradication of illnesses and health hazards. But there is also a stress on providing for our energy needs, improving education, and reducing crime. Concern about education and defense has been increasing significantly in the 1970's, while energy has become one of the foremost concerns of the public, especially of the attentive public.

SPECIFIC ISSUES

Since only a limited segment of the public, the attentive public, concerns itself significantly with science and technology, it is difficult to find issues that have sufficiently wide appeal to measure the total public's opinion regarding scientific endeavor and technological advances. In recent years, however, certain events and developments have re-

[26] Another difference is that the General Social Survey does not say explicitly that the funding is to come from taxes, but only asks whether "we" may be spending too little in certain areas.

[27] *An Analysis of Public Attitudes Toward Technology and Investment*, Union Carbide Corporation, Survey conducted by Cambridge Reports, Inc., 1978, p. 30.

[28] *Attitudes Toward Science*, Report No. 08-S-02 (Denver: National Assessment of Educational Progress, 1979), p. 30.

[29] *Science and European Public Opinion*, p. 54.

[30] Frederic Bon and Daniel Boy, "Les francais et la science," *La Recherche*, vol. 12 (March 1981), pp. 344-352.

[31] There were more respondents who wanted to decrease military and space research than who wanted to increase it.

ceived so much media publicity that their impact has been almost universal. Three of these were singled out for special study.

The first—space exploration—not only has global impact and visibility, but it has elements of drama and international competition. It began over 20 years ago with the Soviet launching of Sputnik, and it spanned a period that included the American moon walks and the exploration of distant planets within view of a world public that watched these events on television. By 1979, both Federal support and mass media coverage of the topic had declined considerably, though media coverage subsequently revived with the transmission of the Saturn photographs to earth in 1980 and the flight of the Columbia space shuttle in 1981.

The second topic—chemical food additives—has, along with environmental pollution, been of continuing concern to the public, although it has never had as dramatic a focus as the walk on the moon or the pictures of Saturn or Mars. Nevertheless, it has received continuing publicity in the press, and many have become alarmed about it. Of greatest concern to the public, when it is faced with questions about chemical food additives, is the implicit threat of cancer. Health care is highest on the list of areas the public would like to receive science- and technology-related tax funding (see table 6-8), and cancer is a major health issue.

The third topic—locating and building nuclear power plants—came to the forefront of public attention with the Three Mile Island incident in 1979. The controversy over the use of nuclear power is relatively recent, but it has reached a particularly high level of intensity.

Space Exploration

While it has considerable intellectual interest and entertainment value, space exploration is not a daily concern of the general public. It has less relevance to personal life than, for instance, the question of chemical food additives or the issue of siting and building nuclear power plants. The levels of interest and information in this area are especially low (see table 6-13). Hence, it is not surprising that the public considers the exploration of space a low-priority area in which to invest the public funds available for science and technology (see table 6-8). Nevertheless, if no comparison is made with other expenditure areas, 60 percent of the public favor the exploration of outer space.[32] This may be because the "space spectaculars" of the 1960's and early 1970's captured the imagination of Americans. A more probable reason, however, is that 71 percent of the public who have heard of controversies in this area feel that benefits are likely to come from exploring outer space, with 42 percent seeing benefits without any harms (see table 6-10).

[32]Miller, Prewitt, and Pearson, *The Attitudes of the U.S. Public Toward Science and Technology*, p. 93.

Table 6-9. Most frequently expected benefits and harms from space exploration: 1979

Benefits	Percent[1]
Improve other technologies (e.g., computers)	39
Increase knowledge of universe and/or man's origins	28
Find mineral or other wealth, other resources, sources of energy	28
Find new areas for future habitation	19
Contact other civilizations, other forms of life	15
	(N = 697)
Harms	**Percent[1]**
Bring back other diseases or problems	30
Disturbs the weather, messing up atmosphere	23
Too expensive, waste of money	22
Falling debris, leaving garbage in space	16
Dangerous for space explorers	13
	(N = 401)

[1]Two responses were accepted for benefits and two for harms. Percentages are based on those who have heard of controversies in this area and who say there are benefits or harms, not on the entire sample.

REFERENCE: Appendix table 6-13. Science Indicators—1980

Table 6-10. Distribution of benefits and harms expected in specific issue areas by attentives and the total public: 1979

Issue area	Percent[1] of	
	Attentives	Total public
Space exploration		
Benefits and no harms	61	42
Both benefits and harms	31	29
Neither benefits nor harms	6	16
Harms and no benefits	3	13
	(N = 252)	(N = 986)
Chemical food additives		
Benefits and no harms	7	10
Both benefits and harms	79	49
Neither benefits nor harms	3	12
Harms and no benefits	12	30
	(N = 294)	(N = 1,504)
Nuclear power plant location		
Benefits and no harms	20	17
Both benefits and harms	50	46
Neither benefits nor harms	0	5
Harms and no benefits	29	32
	(N = 300)	(N = 1,494)

[1]Percentages are based on those who have heard of controversies in each area, not on the entire sample.

REFERENCE: Appendix table 6-14.

Science Indicators — 1980

When the 60 percent of the population who had heard of controversies about space were asked for the two principal benefits of space exploration, the one mentioned most often was improved technologies, such as computers (table 6-9). A significantly larger proportion of the public can list benefits than can list harms. Among the latter, the one mentioned most often is the possibility of bringing diseases back to earth.

The attentive public is more positive about space exploration than is the public as a whole. Of the attentives, 87 percent favor further exploration of outer space,[33] and, of those who have heard of space-related controversies, many more attentives than nonattentives feel there are benefits but no harms in space exploration (table 6-10 and appendix table 6-14). Similarly, the proportion of nonattentives who think there are only harms is much higher than of attentives.

It should be noted that the proportion of people who see only benefits in space exploration is much higher, both in the total public and among attentives, than is the proportion who see only benefits in chemical food additives or in nuclear power plants (table 6-10). Whereas 4 out of 10 members of the public who have heard of related controversies see at least some harms coming from space exploration, the proportion that sees harms in chemical food additives and in nuclear power plants is 8 in 10. For both attentives and nonattentives, space exploration is the only area of the three in which more people see benefits than harms. Thus, space exploration is perceived as the least threatening area.

Food Additives

The topic of food colorings and additives recurs so consistently in the print and the broadcast media that it is not surprising that 92 percent of the public have heard about the controversies surrounding the subject.[34] Almost 80 percent of the public see some harm in food additives, while about 60 percent see some benefit (table 6-10). Almost three out of four respondents say they would make a special effort to avoid products that contain an additive if a group of scientists said the additive caused cancer;[35] 46 percent of the public say they have

[33]Ibid., p. 97.

[34]Ibid., p. 104.
[35]Ibid., p. 108.

actually changed their shopping or eating habits because of reports about possible dangers in food additives.[36]

The public clearly regards the possibility that certain food additives may cause cancer as the greatest risk in using them. This was mentioned far more often than any other harm; next in order was the possibility of acquiring some other disease (table 6-11). Yet there is also wide recognition that chemical food additives retard spoilage and thus prevent some illnesses.

In short, food additives are a mixed blessing as far as the public is concerned. About one-third of those who have heard about the issue consider food additives a very serious problem. Only 10 percent do not consider food additives a problem at all.[37] The fact that only 17 percent of the public consider themselves well informed about food additives and 32 percent are greatly interested in the problem[38] suggests that the public would like to know more about the issues involved. People want to be involved in making decisions about things that affect them as intimately as the food they eat. Another study found that a plurality of 46 percent of the public would rather decide for themselves whether or not to use substances possibly linked with cancer, rather than let government ban some or all of them. Another 43 percent would like government to ban some substances and let the public decide on others. Only 10 percent would like to see all substances linked with cancer banned.[39]

The attentive public is more inclined to see harms in chemical food additives than are nonattentives (appendix table 6-14). This is not true in the other two issue areas. Attentives, like nonattentives, would try to avoid products labeled by scientists as cancer-causing (about 71 percent, in both cases), and slightly more attentives (52 percent) than nonattentives (44 percent) claim to have made changes in their eating or shopping habits because of food additives.[40]

Nuclear Power Plants

With the Three Mile Island events still fresh in the minds of the public, as well as the media coverage of intermittent protests and plant construction and operation problems, examining public attitudes on the issue of the location of nuclear power plants is very timely. In view of all the publicity, it is not surprising that 91 percent of the general public have heard about the controversies over nuclear power plants.[41] Of this number, 63 percent see benefits from the production of nuclear energy (see table 6-10). The two benefits mentioned most often are an increased supply of energy and the production of cheaper energy (table 6-12). However, almost 8 in 10 see possible harmful consequences. The major concerns are the possibility of a nuclear explosion or meltdown and low-level radiation leaks. These are topics widely discussed in the aftermath of the Three Mile Island incident and related dramatizations such as the motion picture, "The China Syndrome." The public's understanding of these consequences is discussed below.

In general, nuclear power plants are a subject of high personal involvement; 62 percent of respondents oppose location of a nuclear power plant in their own areas.[42] Yet, in spite of these concerns, a 1979-80 survey found that 77 percent of the public consider nuclear energy too important to abandon altogether.[43] While 73 percent of the public believe that there is no guarantee against a catastrophic nuclear accident, and 84 percent feel that fundamental regulatory changes are necessary if the risks of nuclear energy are to be kept within tolerable limits, 59 percent disagree with the statement that

[36]Ibid.

[37]Tanfer et al., p. 140.

[38]Text table 6-13.

Table 6-11. Most frequently perceived benefits and harms from chemical food additives: 1979

Benefits	Percent[1]
Improves shelf life, retards spoilage, kills germs, preserves	85
Improves taste, color, consistency, or appearance	35
Improves nutrition, adds vitamins	24
	(N = 891)
Harms	**Percent[1]**
Causes cancer or suspected of causing cancer in laboratory animals or humans	68
Causes other diseases or illnesses, birth defects	31
Generally "not good for you," or "harms the body"	21
	(N = 1,189)

[1]Two responses were accepted for benefits and two for harms. Percentages are based on those who have heard of controversies in this area and who say there are benefits or harms, not on the entire sample.

REFERENCE: Appendix table 6-15.

Science Indicators—1980

[39]*Risk in a Complex Society* (Marsh & McLennan Companies, Inc., 1980), p. 24. Survey conducted by Louis Harris and Associates, Inc., December 1979 to March 1980.

[40]Miller, Prewitt, and Pearson, p. 122.

[41]Ibid., p. 112.

[42]Ibid., p. 115.

[43]*Risk in a Complex Society*, p. 39.

Table 6-12. Most frequently expected benefits and harms from nuclear power plants: 1979

Benefits	Percent[1]
Increase the supply of energy, solve our power shortage	65
Produce cheaper energy, less expensive than other energy sources	35
Reduce importation of foreign oil, reduce balance of payments problems, reduce foreign dependence	12
Improve economy, produce more jobs	8
Rely less on fossil fuels, conserve our fossil fuels	8
	(N = 934)
Harms	**Percent[1]**
Possibility of melt-down, nuclear explosion, or other catastrophic accident—human error leading to accident	45
Low-level radiation leaks to surrounding area	42
Problems in disposal and maintenance of used nuclear material	24
Health risks to nonworkers, genetic risks, danger to unborn children, cancer	22
Heat pollution or other environmental damage	11
	(N = 1,166)

[1]Two responses were accepted for benefits and two for harms. Percentages are based on those who have heard of controversies in this area and who say there are benefits or harms, not on the entire sample.

REFERENCE: Appendix table 6-16.

Science Indicators—1980

"nuclear power is too dangerous to permit its continued expansion." However, 57 percent would countenance a temporary ban on licensing new nuclear power plants, regardless of their location.

Numerous surveys in recent years, both in the United States and abroad, have shown similar patterns.[44] In the United States, more people have favored building nuclear power plants than have opposed it, except in October and November 1979. This was the time of the release of the Kemeny Commission Report, about 6 months after the Three Mile Island incident (figure 6-1). The figure shows some loss of support for nuclear power and some increased opposition even before Three Mile Island. It also shows a decrease in the fraction of the public who are "not sure" about nuclear power. Most of those who left this declining undecided group seem to have moved into opposition to nuclear power. Since the last poll prior to Three Mile Island, support for nuclear power has noticeably decreased and opposition has noticeably increased, but the balance is still on the side of support.

Sentiment toward the building of a nuclear power plant within 5 miles of one's own community is generally less favorable than sentiment toward nuclear siting regardless of location (see appendix table 6-18). A study conducted in early 1980 showed that Americans on the average are willing to live nearer to a supervised disposal site for hazardous chemical wastes than to a nuclear power plant. They are willing to live much closer to a large factory or a coal-burning power plant.[45] Similar studies have been done in France and Japan. Opposition to nuclear power in Japan was 29 percent in June 1979, while support was 50 percent. However, when the question was about a nuclear plant in the vicinity of the respondent's home, opposition was 67 percent and support only 18 percent. The response in France was different. In April 1979, those who lived near a nuclear plant were not significantly more opposed to nuclear power than the total French population. In fact, more of the former (30 percent vs. 22 percent) said they would hardly be disturbed by the building of a new plant near their homes.[46]

Significantly fewer attentives (51 percent) than nonattentives (64 percent) oppose the location of nuclear power plants in their areas.[47] However, attentives are peculiarly polarized on the nuclear issue. Of those attentives who have heard of nuclear controversies and could mention related benefits and harms, 20 percent thought there were benefits without harms and 29 percent thought there were harms without benefits (appendix table 6-14). The other two issue areas did not have so many attentives taking these extreme positions.[48]

The special issue areas considered here have received much publicity in the press and have been widely discussed. Food additives are of con-

[44]See R. C. Mitchell, "The Public Response to Three Mile Island: A Compilation of Public Opinion Data About Nuclear Energy" (Washington, D.C.: Resources for the Future, November 16, 1979), Discussion Paper D-58, pp. I-10, I-11, I-13, I-20, I-22. Swedes have been more consistently opposed than Americans, Canadians, Germans, Japanese, or the French. Also see R. C. Mitchell, "Polling on Nuclear Power: A Critique of the Polls After Three Mile Island," in Albert H. Cantril, ed., *Polling on the Issues* (Washington: Seven Locks Press, 1980), pp. 66-98, and Roger E. Kasperson et al., "Public Opposition to Nuclear Energy: Retrospect and Prospect," *Science, Technology, and Human Values*, vol. 5 (Spring 1980), pp. 11-23.

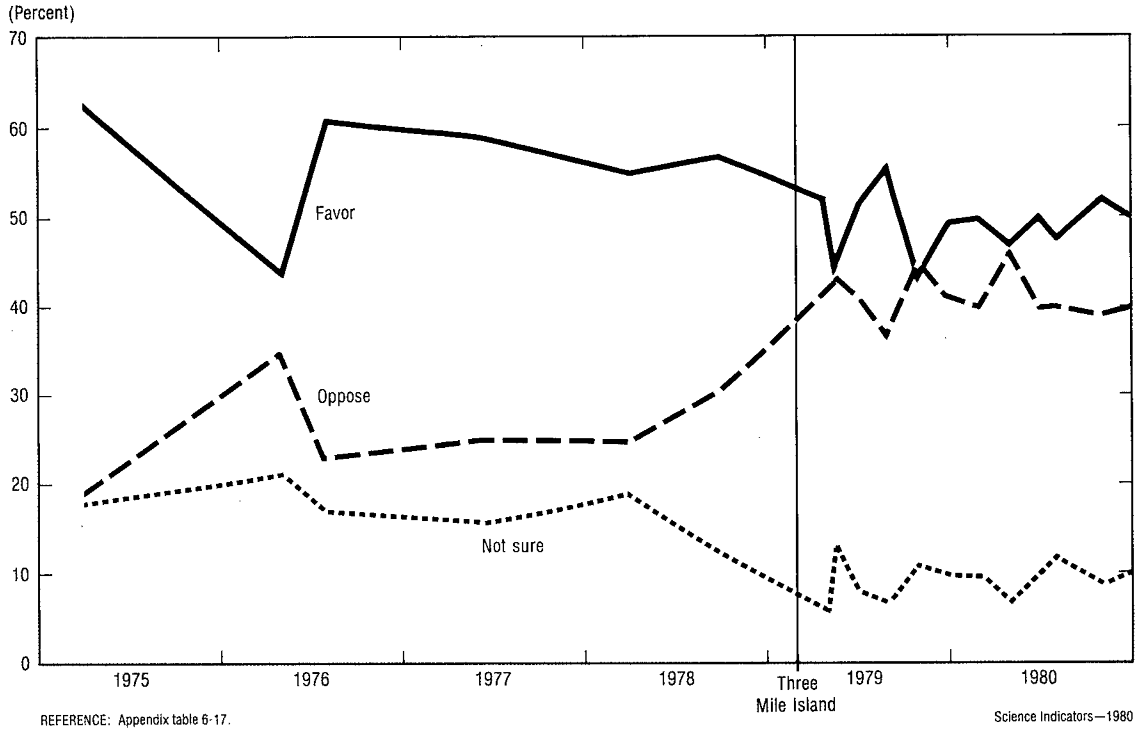
[45]Resources for the Future, *National Environmental Survey, Final Results*, p. 6.

[46]R. C. Mitchell, pp. I-1, I-14, I-20.

[47]Miller, Prewitt, and Pearson, p. 115.

[48]In France, repondents were asked in 1972 and 1980 how much confidence they would have in scientists who declared that a certain nuclear power facility would be safe. There was no great change in the response of the whole sample over this period, but there was a marked decrease in the confidence expressed by those at the highest educational level. This group parallels the attentive public in the U.S. study. See Bon and Boy, p. 348.

Figure 6-1
Portion of the U.S. public favoring or opposing the building of more nuclear power plants in the United States



REFERENCE: Appendix table 6-17.

Science Indicators—1980

cern to the public because of the possibility of disease. Thus, more respondents saw harmful effects from this technology than saw benefits. Space exploration elicits evident interest from the public, but it is not a dominant concern when weighed against other areas for public spending. While it is the least important area to most people, it is also seen as the least dangerous. More people see harms than see benefits in nuclear power. Still, most people support it, though they would not want to live near a nuclear plant. Attentives see more benefits in the three areas than do nonattentives. In the case of food additives, they also see more harms. With regard to the siting of nuclear plants, their perception of benefits and harms is much like that of the nonattentive public, and there is a high level of disagreement among attentives on this point. However, fewer attentives than nonattentives are actually opposed to nuclear plants. Attentives support space exploration considerably more than nonattentives do.

Much depends on the amount of information the public has, or feels it has, about an issue. The following questions may well be asked: Do people participate more widely in controversies on which they are better informed? What topics do people feel they are well informed about? With more people claiming to be informed on a topic, do more people also want to make policy decisions on that topic? These questions will be discussed in the next section.

PUBLIC PARTICIPATION IN ISSUES

Willingness to Participate

One must have some information about a topic before one can take an interest in it. Hence, it is not surprising that interest and information appear to run parallel for the three specific issues discussed above, increasing as one goes from space exploration to chemical food additives to the location of nuclear power plants. In all three cases, there is a direct relationship between the number of people who express an interest in an issue and the number who indicate that they are informed about that issue (table 6-13). In the cases of space exploration and the location of nuclear power plants, for which data are available, the predisposition to get involved in the controversy also bears a direct

Table 6-13. Interest, level of information, and personal involvement regarding specific issue areas among attentives and the total public: 1979

Issue area	Percent of attentives	Percent of total public
	(N = 301)	(N = 1,635)
Greatly interested in:		
Space exploration	34	15
Chemical food additives	46	32
Nuclear power plants	57	33
Well informed about:		
Space exploration	24	9
Chemical food additives	29	17
Nuclear power plants	39	17
Would definitely take an active part in controversies about:		
Space exploration	12	7
Nuclear power plants	39	24

REFERENCE: Appendix table 6-19.

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Table 6-14. Reasons given for not wishing to take an active part in specific issue controversies: 1979

Reason given	Percent offering reason[1]	
	Space controversy	Nuclear plant controversy
I don't know enough about the issue	69	59
It wouldn't do any good	30	32
I wouldn't know who to contact	22	15
I have too many other things to do	19	19
Someone else would probably express my views	15	19
It would not affect me personally	14	10
	(N = 1,068)	(N = 627)

[1]Percents are based on those who said they would not participate, not on the entire sample. Multiple responses were accepted under each controversy, so that the percentages add to more than 100.

SOURCE: Koray Tanfer, Eugene Ericksen, and Lee Robeson, *National Survey of the Attitudes of the U. S. Public Toward Science and Technology.* Volume II: Detailed Findings (Philadelphia: Institute for Survey Research, Temple University, 1980), pp. 163-169, 188-194.

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relation both to level of interest and to level of information.

It is reasonable to assume that the public would refrain from participation in a controversy about which it lacks adequate information. This is precisely how the public reacts to a hypothetical conflict involving scientists who want to send a message to a civilization in outer space. Only 9 percent of the public feel well informed about space controversies, and only 7 percent say they would take an active part in the hypothetical conflict (table 6-13). In the case of building a nuclear power plant, both the reported level of information and the willingness to participate are higher. In this case, the number that would definitely participate[49] is greater than the number considering itself well

[49]Larger numbers respond that they "would probably participate."

Table 6-15. Groups perceived to be most and least qualified to make specialized decisions: 1979

Group	Percent[1] regarding group as most qualified			Percent regarding group as least qualified		
	On space communication	On food additives	On nuclear plant	On space communication	On food additives	On nuclear plant
Scientists/engineers	69	82	59	2	0	2
Federal agency	66	44	32	3	3	3
Citizens	17	27	45	21	19	16
Business/industry	NA	23	20	NA	21	29
President/Congress	15	4	5	7	15	12
United Nations	15	NA	NA	8	NA	NA
Local government	3	4	16	26	16	10
Governor/State legislature	3	3	9	5	5	4
Courts	2	4	7	24	16	20

[1]Includes first and second choices.

NA = Not asked.

NOTE: Sample size was 1,635 for all questions.

SOURCE: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U. S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), pp. 260, 261, 265-266, 272-273.

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informed, though it is still below the number that is greatly interested. Thus the nuclear issue is salient enough to attract participants who do not consider themselves well informed.[50] In general, both knowledge and personal interest seem to contribute to a willingness to take part in a controversy. For both issues, those who say they would not participate overwhelmingly give "I don't know enough about the issue" as a reason (table 6-14). Since attentives consider themselves to be better informed on these topics, and are more interested, they are also more likely to participate than is the rest of the public. The issues fall in the same order for attentives as for the public at large, in terms of interest, information, and willingness to participate (table 6-13).

The general sense of insufficient information prevalent in the public is an important factor in whether the public feels qualified to participate actively in scientific controversies. Given a lack of information, to whom does the public look for expertise and guidance?

Competence of Various Participants

When it comes to specific issues that are clearly in the scientific or technological domain, the public is unequivocal in recognizing first of all the expertise of scientists and engineers (table 6-15). Normally, it will also recognize, but to a slightly lesser degree, the Federal specialized or regulatory agency that has responsibility in a particular field.[51]

The proportion of the public that considers citizens themselves best qualified to decide a specific issue depends on the amount of public involvement there has been and the amount of personal risk that is thought to be at stake. The more public concern there is about an issue, the more the public wants to take an active part, and the less it wants to leave the decision to Federal agencies or commissions (table 6-15).[52] Thus, while the public places itself third on the list in the case of space exploration or food additives, it regards itself as the group second most qualified to decide in the case of nuclear power plant siting.

Earlier studies show that scientists and engineers have for some time had the confidence of a substantial segment of the United States population. Even among the nearly 80 percent of the public in 1976 who felt that science and technology had caused at least a few of the Nation's problems, only

[50]This happens particularly among nonattentives (appendix table 6-19).

[51]It should be stressed, however, that this is more a willingness to acknowledge the competence of the specialized agencies than trust in the Government in general. Only about a third of the public trusts the Federal Government to do what is right almost always or most of the time. See Tanfer et al., p. 238.

[52]A similar result was found in Todd La Porte and Daniel Metlay, op. cit.

5 percent and 7 percent, respectively, blamed scientists and engineers for the problems.[53]

When a large segment of the public places itself second or third on the list of those competent to decide an issue (see table 6-15), it appears to do so because it considers itself an interested party in the controversy. This is especially true in the case of nuclear power. On the other hand, the public also places itself high on the list of those least qualified to participate. This seems to be due to a perceived lack of knowledge, the most frequent reason given by the public for not wishing to participate in these issues (see table 6-14).

There is further evidence that the public feels it lacks knowledge about science and technology, since 86 percent express the view that most citizens are not well enough informed to help set goals for scientific research, and 85 percent say most citizens are not sufficiently informed to decide which new technologies should be developed.[54] Only 11 percent think most citizens are well enough informed to set goals for scientific research, and 12 percent feel that they are well enough informed to decide on new technologies. In this respect, Americans are similar to respondents from nine Western European countries, two-thirds of whom said they had difficulty talking about science "because I don't know enough about it."[55]

In view of the extensive publicity about nuclear energy, it is worthwhile to ask how knowledgeable people have become about it. Half the adult population claims to have a clear understanding of the word "radiation," and another 44 percent say they have a general sense of what is meant.[56] Yet in April and May of 1979 only one-third of the public, even after the Three Mile Island mishap, appeared to know that reactors could not possibly cause an atomic bomblike explosion.[57]

Science and technology are far from being the only areas of public policy about which people feel uninformed.[58] An average of 86 percent of Americans feel less than very well informed about nine different policy areas. Areas related to science and technology are among the ones that the public knows the least about, but generally the public claims to know little about any of the areas (appendix table 6-20). Thus the question can be raised as to whether the public is receiving enough scientific and technical information to enable it to deal with an increasingly technical world.

In summary, public willingness to participate in controversies regarding scientific and technological issues varies according to the degree of interest in and the amount of information on the issues available to the public. Interest and information also are interrelated from one issue to another. The more informed the public believes it is on an issue, the more likely it is to consider itself qualified to participate actively in a controversy. In the case of nuclear power, the number willing to participate is greater than the number considering itself well informed. In the other two areas, the perceived qualification of Federal specialized and regulatory agencies is greater than the perceived qualification of the public. However, scientists and engineers are always ranked first in qualification. Almost twice as many attentives as nonattentives say they would definitely involve themselves in a controversy. This being the case, it is important to determine who these attentives are and how they get to be that way.

THE ATTENTIVE PUBLIC

Composition of the Attentive Public

Table 6-16 shows the characteristics of the attentive public for science and technology identified by the method mentioned earlier. One should note that column three breaks down the attentives by various demographic characteristics and is dependent on the overall demographic composition of the public. For example, 55 percent of all people with graduate degrees can be classified as attentive. However, since only a small portion of the public has this level of education, persons with graduate degrees make up only 17 percent of all attentives. On the other hand, since a large portion of the U.S. population is in the 18-to-34 age group, the 24 percent of the people in this age range who are attentive represent 53 percent of all attentives.

[53]Opinion Research Corporation, pp. 19-20. On the other hand, 42 percent of respondents agreed in 1979 that "you can't trust what the experts like scientists and technical people say because often what they say isn't right" (from an NBC/Associated Press poll, April 30-May 1, 1979, in Robert C. Mitchell, "The Public Response to Three Mile Island: A Compilation of Public Opinion Data About Nuclear Energy," p. III-2).

[54]Tanfer et al., pp. 232 and 233.

[55]*The European Public's Attitudes to Scientific and Technical Development*, p. 24.

[56]Tanfer et al., p. 201.

[57]Robert C. Mitchell, "Public Opinion About Nuclear Power and the Accident at Three Mile Island" (Washington: Resources for the Future, 1979), Discussion paper D-60, pp. 4-5; *Public Opinion on Environmental Issues*, President's Council on Environmental Quality, 1980, p. 36. The survey reported in the latter source found a generally low level of public knowledge with respect to energy and environmental issues.

[58]See P. E. Converse, "New Dimensions of Meaning for Cross-Section Sample Surveys in Politics," *International Social Science Journal*, vol. 16 (1964), pp. 19-34.

Table 6-16. Composition of the attentive public: 1979

Group	Percent of group found to be attentives	Percent of attentives who are in group	Sample size
All adults	18	100	1,635
By education:			
Less than high school	4	6	465
High-school diploma	12	22	550
Some college, no degree	28	35	382
Bachelor's degree	43	21	146
Graduate degree	55	17	92
By sex:			
Female	13	38	862
Male	24	62	773
By age:			
18-34	24	53	670
35-54	17	28	492
55 and over	12	19	473

SOURCE: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U. S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), p. 46.

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It may be noted that the proportion of persons who are attentive is significantly greater in the more highly educated groups and in the lower age groups.[59] Statistical analysis shows that of five characteristics that might explain who falls into the attentive-public category, education has by far the largest effect.[60] Other significant predictors of attentiveness are political activism,[61] maleness, and youth (i.e., being between 18 and 34 years of age).[62] Research-related employment is found to have little effect. Younger people tend to be more attentive, in spite of the fact that they are less politically active.

Analysis of a similar study in 1957 showed the same levels of attentiveness to science and technology as in 1979 among persons with a high-school diploma or less education (appendix table 6-21).[63] On the other hand, the proportion of attentives among those with some college has increased from 24 to 36 percent. Since the number of people who have college degrees or have at least attended college has also risen appreciably since 1957, the number of attentives with some college has gone up dramatically. At the same time, while the proportions of men and women in the attentive

[59]If 10-year age ranges are taken, persons aged 25 to 34 are found to be considerably more attentive than any other age group. See Miller, Prewitt, and Pearson, p. 46.

[60]To assess the relationship between attentiveness and the variables of education, political activity, age, sex, and research-related employment, Goodman's "logit model" and path analysis were used. The logit model is a log linear analysis that ignores intercorrelations among the independent variables. Path analysis considers these intercorrelations and shows the direct and indirect contributions of the independent variables to attentiveness. The Goodman logit model shows that 71 percent of the mutual dependence is accounted for by the five independent variables used in the model. For a description of Goodman models, see L. A. Goodman, "A General Model for the Analysis of Surveys," *American Journal of Sociology*, vol. 77 (1972), pp. 1035-1086.

[61]Political activism is measured by whether a person has recently voted, worked for a political candidate, attended political meetings, or asked people to vote for a candidate.

[62]Miller, Prewitt, and Pearson, pp. 53-54. In a comparable study in France in 1972, the single criterion of education was used to measure attentiveness. See Fondation Nationale des Sciences Politiques, "Les attitudes de l'opinion publique a l'egard de la recherche," *Le Progres Scientifique*, No. 165-166 (August-October 1973).

[63]Appendix table 6-21 compares the attentives in 1979 with those in 1957. Different individuals are involved in the two surveys, but the criteria for attentiveness were made as similar as possible.

public may have differed little in 1957, the gap seems to have widened, with men being more likely than women to belong to the group at present.

Development of Attentiveness

If 18 percent of the general public are attentive to science and technology, when and why do they get to be that way? The growth and development of attentiveness to these subjects from youth to adulthood may be traced with the help of a related study.[64] Through an index developed along the same lines as for the present study, it was found that at the end of their high-school careers, college-bound high-school students are more attentive to science and technology than non-college-bound students are (figure 6-2). For both, attentiveness to technology is notably greater than attentiveness to science. College-bound students actually seem to decrease in overall attentiveness during their high-school years.

As the figure shows, during the college years there is a substantial rise in the number of students attentive to both science and technology, perhaps as a result of science course requirements. Attentiveness to either science or technology increases from approximately one-fourth of the freshman class to about one-third of the senior class.[65]

These results are important in judging the adequacy of U.S. educational institutions in training scientists and engineers and citizens in general. If enough students do not become attentive to science and technology, the number of good students in these fields is bound to be insufficient. It is also important for those who will not become scientists or engineers to acquire some understanding of these fields during their school years.

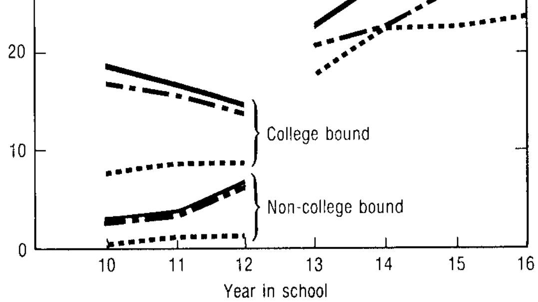
Insights on how young people develop in their understanding of science may be gained from another cross-sectional study conducted with 13- to 35-year-olds in 1976 and 1977.[66] From age 13 to age 17, an increased level of awareness was found of the nature and methods of scientific investigation. For young adults aged 26-35 there appears to be no greater sophistication, except that persons in this older group are more likely to support the idea that scientists should criticize one another's work and allow others to dispute their theories.

The older respondents expressed more satisfaction or hope with regard to science and technology and much less indifference. There is little difference in the more extreme reactions of excitement or wonder, or fear or alarm, at different ages (appendix table 6-22).

In sum, more than half of those attentive to science and technology in the American public are in the 18-to-34 age bracket. Education is the single characteristic most closely associated with attentiveness. Since 1957, the percentage of attentives in the population has doubled because of an increase in attentiveness among those who have at least some college education and because the actual number in the population of those who have attended college has risen appreciably. For those who attend college, attentiveness to science and technology increases in college but not in high school.

Figure 6-2

Percentage of high school and college students attentive to science, to technology, or to either science or technology: 1978



REFERENCE. Appendix table 6-23.   Science Indicators—1980

[64] J. D. Miller, R. W. Suchner, and A. M. Voelker, *Citizenship in an Age of Science* (New York: Pergamon, 1980).

[65] It is important to note that the investigation surveyed different individuals at different grade levels rather than following the same individuals through various grades. Also, students drop out from year to year, so that those surveyed later in their educational careers are probably better and more highly motivated. This in itself would make a small contribution to the higher attentiveness seen in later years. The attentiveness of students may also be influenced by contemporary political events that they have experienced.

[66] National Assessment of Educational Progress, *Attitudes Toward Science*. Report No. 08-S-02 (Denver: Education Commission of the States, 1979), pp. 41-43.

OVERVIEW

The general attitude of the American public toward science and technology is strongly favorable, though this feeling of support has declined since the late 1950's. Most Americans credit science with important contributions to the high standard of living in the United States and feel that the benefits of science considerably outweigh the harmful consequences. U.S. technological and industrial know-how are seen as the single greatest source of U.S. influence in the world, and scientific creativity is viewed as another major source of U.S. world prestige. The public is unequivocal in recognizing the primary qualifications of scientists and engineers to act as decisionmakers on three specific science and technology issues. On these issues citizens rank themselves second to scientists and engineers in competency to make decisions regarding the location of nuclear plants and third in issues related to space exploration and chemical food additives.

The public looks to science and technology for solutions to many of its problems concerning health, energy, and natural disasters. Specifically, scientific and technological achievements are expected to provide more efficient sources of cheap energy, a cure for common forms of cancer, and the ability to predict when and where earthquakes will occur. At least 9 out of 10 people consider it possible that these three major problems will be resolved within 25 years. Fewer believe that research will be able to reduce the crime rate or lead to putting communities of people in outer space.

When it comes to actually spending its tax dollars, the American public is supportive of research and development in many of these same areas. The science and technology areas which the public would prefer to receive Federal funding are those concerned with improving health care, developing energy sources and conserving energy, and improving education. There is also strong support for efforts to reduce crime, though there is little optimism about the likelihood that science and technology will achieve this. Since the early 1970's, defense has risen considerably as a priority area for science and technology funding. However, discovering new basic knowledge gets relatively low funding priority.

Significant portions of the American public see some negative sides to the impacts of science, especially its effect on personal values and the respondents' way of life. More than half the public thinks that scientific discoveries make our lives change too fast. However, the majority of Americans generally do not wish to limit scientific inquiry. In particular, they strongly support studies aimed at being able to detect criminal tendencies in very young children. On the other hand, they are opposed to studies that might allow scientists to create new forms of life.

About one-fifth of the public is regularly interested in, and knowledgeable about, science and technology. Such people usually have attended college, or are male, or are under 35 years of age. This attentive public differs from the general public in that it tends to view scientific investigation as more beneficial, and is less inclined to restrict scientific inquiry. In terms of how tax dollars should be spent, the attentive public gives higher priority than does the general public to developing energy sources and conserving energy, reducing and controlling pollution, discovering new basic knowledge about man and nature, and exploring outer space. Attentives are not only informed about science and technology; they are also nearly twice as likely to involve themselves in a science and technology controversy as are nonattentives. The proportion of attentives in the general population has doubled since 1957. College attendance does more than high-school attendance to raise students' level of attentiveness.

Continued exploration of outer space is supported by 60 percent of the total public and by 87 percent of the attentives. The benefits seen in space exploration considerably outweigh the harms. Some benefits are seen in chemical food additives, but there is considerable fear that they may cause disease. Nuclear power is a great public concern. While the public sees harms coming from it more often than benefits, and is unhappy about the prospect of living near a nuclear reactor, more people favor than oppose building nuclear reactors. Many attentives see only benefits or only harms in nuclear power technology.

In sum, general support for scientists and engineers and for their work remains high. More people than ever before, both in actual numbers and as a proportion of the total population, are interested in, are informed about, and keep up with science and technology. And the attentives, though still a minority, are especially supportive of the scientific community and hold high expectations for future results.

Chapter 7
Advances in Science

Advances in Science

INTRODUCTION

This chapter presents a descriptive sampler of some recent and significant achievements of scientific and engineering research in several selected areas. Some of the benefits of these advances are in the direct daily experience of the average citizen, and some are hidden in the infrastructure of our technological society, yet all have a profound influence on the life of the citizenry. A qualitative account of the development and nature of some of these advances can give a deeper appreciation of the nature and the need for scientific and engineering research, beyond the quantitative analyses of previous *Science Indicators* reports.

This chapter represents a first attempt to provide for a *Science Indicators* report extensive supplementary, descriptive material to provide a more complete picture of the research process and some of its products. Most quantitative indicators fail to capture qualitative aspects of the entities they measure or do not describe the complexities and nuances of the processes involved. These limitations had become increasingly evident in the earlier editions of *Science Indicators* which covered quantitative input and output measures in order to present an overview of the status of U.S. science and technology.

These vignettes indicate the progress made in a few areas of science, selected to provide a better understanding of the evolutionary and complementary nature of research and the remarkable rate of progress evident in recent years. The individual research accomplishments described are recent, represent significant contributions to the immediate advancement of knowledge, and show considerable potential for practical applications. It is important to realize that the scientific accomplishments described here do not represent a comprehensive summary of recent developments in all fields of science, nor are they a list of all the most important recent advances. Furthermore, it should be noted that the research described is funded by a variety of sponsors, with the Federal Government generally playing a key role.

The essays show clearly that science and technology depend not only on the magnitude of funds and the number of individuals involved but also on the ingenuity and perception of the investigators. Furthermore, it is clear that systematic, programed activity is only part of the research process. Quite often, striking progress is made by a chance correlation by a researcher new to a field. At other times, progress is achieved by crossing boundaries between fields or by introducing new and more powerful instrumentation or methodologies. Progress in research is highly dependent on fresh approaches, insights, and sometimes on chance.

ASTRONOMY

Throughout history, mankind has been fascinated by the heavens. The numerous references to cosmic objects and phenomena that appear in the written records of humanity attest to its impact on societies through the ages. Intertwined with societal concepts, astronomy has served as one focal point for understanding the nature of the cosmos.

The technological revolution of the present era has led to developments in astronomy and astrophysics that command wide public attention. New techniques and new instrumentation provide astronomers direct observational access to objects and physical processes once "known" only in theory or imagination—or altogether inconceivable. Such terms as quasars, pulsars, black holes, and gravity waves have become part of our language as science has uncovered these bizarre features of the universe.

Two of these phenomena, and one not so bizarre but no less fascinating, are of particular current interest: black holes—at present more a useful concept than a demonstrated reality; gravity waves—they must be there but are so difficult to observe; and our nearest star—the Sun.

Black Holes

It is difficult to conceive of a more exotic physical phenomenon than black holes. Yet, unusual though they may be, their nature and genesis are thought to be fairly well understood and can be described in terms of Einstein's General Theory of Relativity. A black hole is a hypothetical object so

compact and dense that the pull of gravity allows nothing, not even light, to escape. Anything that enters a black hole must disappear from view. So, black holes never will be directly observed, no matter how sophisticated the telescope.

Why, then, do astronomers suspect that black holes may exist? The same intense gravitation that makes a black hole black also can attract and swallow neighboring gas, dust, and even whole stars. In such cases, the violent interaction that occurs at the edge (or event horizon) of the black hole should cause observable disturbances. On the basis of these effects, astronomers have identified a number of black hole candidates.

One leading example lies at the center of the large elliptical galaxy named M87. Astronomers' attention was attracted to M87 because it radiates much more energy than other galaxies of the same type. Its core is a strong source of radio waves, and optical astronomers have seen what appear to be jets of matter ejected from the core into intergalactic space. Such violent activity implies a concentrated source of energy at the center of that galaxy.

Further evidence of M87's violence and the possible existence of a black hole there came in 1978 when astronomers using the 200-inch (5-meter) Hale telescope on Mt. Palomar and the 158-inch (4-meter) Mayall telescope on Kitt Peak observed extremely energetic events in its central core.[1] Analysis of spectral measurements of the light from the cluster of stars surrounding the M87 nucleus yielded the startling conclusion that the stars were moving at speeds up to a million kilometers per hour. For this to happen, scientists theorized, an extremely massive, compact, central object—3 billion to 5 billion times more massive than the Sun—would have to be there.

If that were the case, physical theory closely predicts the amount of light that should be emitted from the galaxy's core. But only about one-tenth of the predicted amount was detected, a discrepancy that could be explained if the mass is not composed of luminous stars and gas but is instead a massive black hole.

Another black hole candidate is the powerful X-ray source named Cygnus X-1, in the constellation of Cygnus. It is known to be an X-ray-emitting binary star system, consisting of a normal blue supergiant star orbiting an unseen companion. The blue star, with a mass about 15 times that of the Sun, rotates in orbit about its companion once every 5.6 days. This suggests that the dark companion's mass is at least four times and most probably eight times that of the Sun. A normal star of such mass would be large enough to be visible; because the dark companion is not, it might be a black hole.

The source of X-rays in Cygnus X-1 would be not the black hole itself but a region near its event horizon. The intense gravitational field of the dark companion pulls gas from the blue star. As it swirls around, the gas is heated to very high temperatures and falls into the black hole where it emits high energy X-rays.

Gravity Waves

Most of the information astronomers use to study the universe comes in the form of electromagnetic radiation resulting from acceleration or deceleration of electric charges. This radiation includes gamma rays, X-rays, ultraviolet light, visible light, infrared radiation, millimeter waves, and long wavelength radio waves. These forms differ only in their wavelengths—from the very short gamma rays (about 0.000000001 centimeter) to radio waves many meters to several kilometers long.

In 1916, Einstein hypothesized in his General Theory of Relativity an entirely different kind of radiation—gravity waves that derive from and affect all masses in the universe. Caused by any change in the amount or location of matter, gravity waves could result from the sudden disappearance of matter into a black hole, a large stellar explosion (a supernova), or the rapid orbital rotation of two stars or other massive objects.

As they propagate through the universe, gravity waves cause oscillating ripples in space itself. The size, shape, and relative positions of any objects in their path are distorted. Scientists hoped this effect would provide the means to detect any gravity waves that might be passing our way. Physicists' standard approach has been to suspend a large mass, such as several tons of aluminum, in isolation from vibration and disturbance and to observe closely any distortions in its shape or position. So far, all such earthbound efforts have failed, because the waves, if they exist as predicted, are likely to be extremely weak.

The first experimental evidence lending support to the existence of gravity waves was announced by J. H. Taylor from the University of Massachusetts at a December 1978 scientific meeting in Munich, Germany.[2] This discovery was based on

[1] W. L. W. Sargent et al., "Dynamical Evidence for a Central Mass Concentration in the Galaxy 1987," *Astrophysical Journal*, vol. 221 (1978), pp. 731-744.

[2] J. H. Taylor, L. A. Fowler, and P. M. McCulloch, "Measurements of General Relativistic Effects in the Binary Pulsar PSR 1913+16," *Nature*, vol. 277 (1979), pp. 437-440.

measurements, made over more than 4 years, of the general relativistic effects in the arrival times of pulses from the double pulsar system PSR 1913+16, located some 15,000 light-years from Earth. This pulsar, an object emitting short bursts of radio wave energy, was discovered in 1974 by the same University of Massachusetts research group, using the 1,000-foot (300-meter) radiotelescope of the National Astronomy and Ionosphere Center near Arecibo, Puerto Rico.

The pulsar is known to orbit another massive object because its pulses speed up and slow down with a period of a little less than 8 hours. Of the 328 pulsars discovered to date, PSR 1913+16 alone is known to be in such a short-period orbit around another object that the relativistic effects are large enough to detect. This makes it a unique tool for experimental astrophysics.

Such a system, according to Einstein's theory, should emit gravity waves that slowly extract energy from the orbital motion of the pulsar around its companion. This energy loss causes the two stars to move closer together, decreasing the size of the orbit and the time needed for the pulsar to complete an orbit. The predicted change in orbital period is only about 0.0001 seconds per year more than it would be without the emission of gravity waves. But even such a small time difference can be accurately measured, and has been. In the 5 years from 1974 to 1979, the change of the period was almost precisely the correct value—about 0.0005 seconds.

This result gives important support to Einstein's theory, more than 60 years after it was first announced. Also, it has given new incentive to many physicists around the world working to develop telescopes capable of detecting gravity waves. Perhaps, in the more distant future, the data collected from PSR 1913+16 may lead to development of gravitational wave astronomy.

The Sun

In effect, the Sun is an enormous heat engine, consuming 4 million tons of fuel every second. Even though the Sun is 150 million kilometers

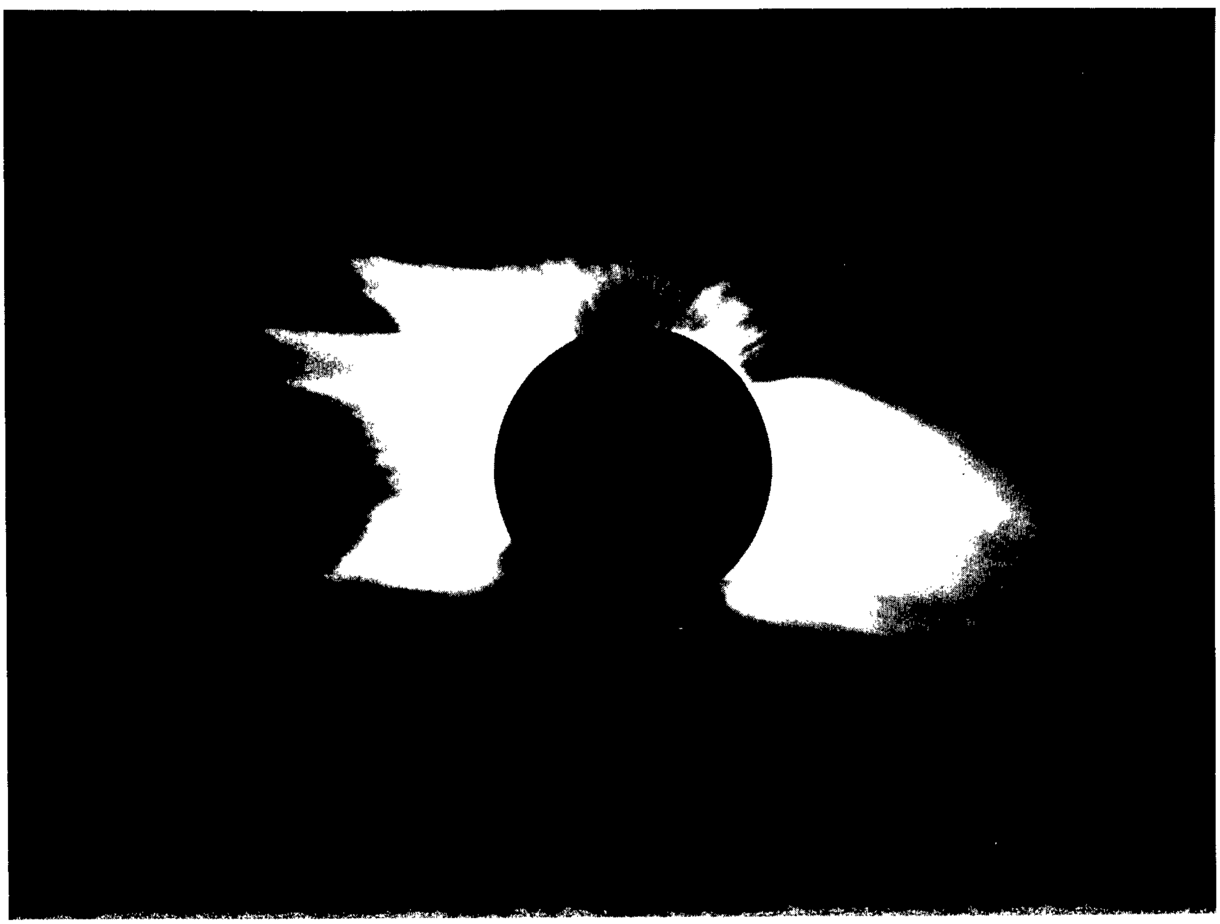


Figure 7-1 **Solar Activity**

from Earth, its energy output is so great that as much as 1.5 million kilowatts of solar power fall on a square kilometer of the Earth's surface.

To the casual observer, the Sun is a quiescent steady source of light and heat, but astronomers long have been aware of large-scale violent events on its surface. Sunspots, solar flares, and the solar wind, for example, are surface signs of the continuous activity within the Sun's interior (figure 7-1). With new observing techniques and developments in solar theory, astronomers have made some important discoveries in recent years.

Coronal Holes: Most of the Sun is covered by a "lid" of closed magnetic fields that impedes the flow of solar material from the corona (its hot outer atmosphere) into space. But the corona has holes in it, as was shown most convincingly by NASA's Skylab mission. These holes occur where the magnetic fields are locally opened, allowing the hot coronal gas to pour out into space (figure 7-2).

What happens when this gas escapes? One study of coronal holes made it clear that the effects are noticed on earth. Using both satellite and ground-based observations, scientists at Sacramento Peak Observatory and Kitt Peak National Observatory, working with others at the Naval Research Laboratory and Los Alamos Scientific Laboratories, found that coronal holes produce high-velocity solar winds and thus cause many of the geomagnetic storms in the Earth's ionosphere.[3] Ground-based solar telescopes now can be used to predict several days in advance the onset of these magnetic storms and the corresponding disturbances to long-range radio broadcasts.

The solar wind, observed by NASA's Voyager 1 and 2 and Pioneer 10 and 11 spacecrafts, is seen to blow far out in interplanetary space. Pioneer 10 crossed the orbit of Uranus in 1979 and is now more than 350 billion kilometers from Earth.

Subsurface Rotation: The number of sunspots on the Sun's surface increases and decreases on an

[3] J. Zirken (ed.), *Coronal Holes and High Speed Winds* (Boulder, Col.: Colorado Association University Press, 1977).

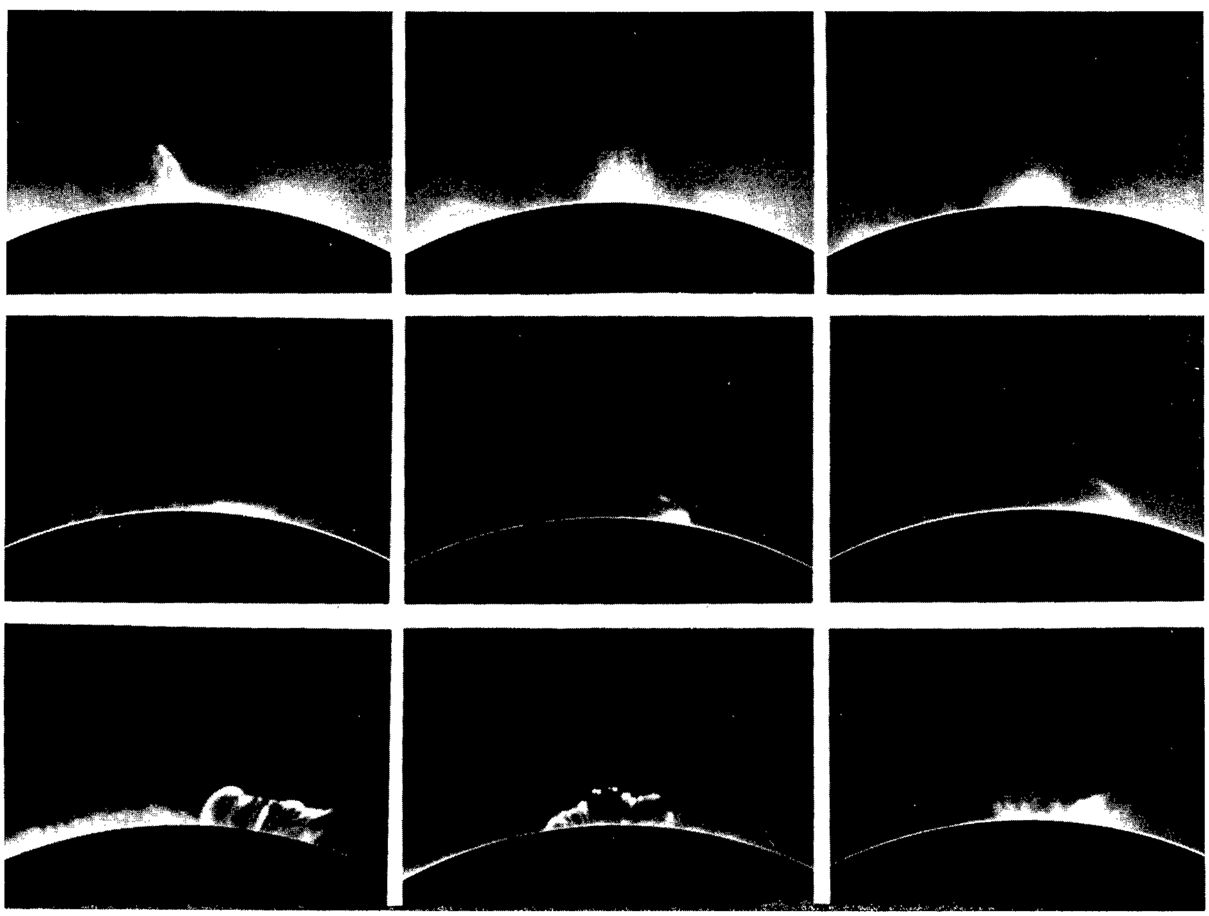


Figure 7-2 **Solar Corona**

11-year cycle. This sunspot cycle is thought to derive from the coupling of solar rotation to strong magnetic fields within the Sun's interior. Some solar theories account for the observed regularities of sunspot positions throughout the cycle by assuming that the Sun rotates faster deep within its interior than it does on the surface. Because observers can see only the outer layers of the Sun, until recently it seemed impossible to determine internal rotation of the Sun to prove or disprove these theories.

Recently, the movement of sunspots across the face of the rotating Sun has been observed by P. Foukal with a specially designed telescope (a solar coronagraph) at the Sacramento Peak Observatory.[4] These observations confirm to high precision earlier indications that sunspots move at a rate 5 percent faster than the gas at the Sun's visible surface (the photosphere). Because these spots have been shown to consist of deeply rooted magnetic fields, this result indicates that the Sun's rotation rate increases with depth below its surface. According to an analysis using a simple dynamic model, the gas about 15,000 kilometers below the photosphere must rotate approximately 100 meters per second faster than gases at the Sun's surface.

A second method to detect internal rotation, devised by F. L. Deubner at Sacramento Peak Observatory, is based on observations of the rapid oscillations of the visible surface.[5] Until recently, astronomers thought these changes were locally excited by randomly rising and falling gas bubbles near the solar surface. However, Deubner has proven that these 5-minute oscillations represent a stable, global system of sound waves that are trapped in a zone under the photosphere. The power contained in the oscillations falls into several discrete wavelength bands, each representing a fundamental mode of vibration.

In addition, using a theory developed by R. K. Ulrich of the University of California at Los Angeles, Deubner found that this result also implies an increase of rotational velocity within the Sun of about 100 meters per second within 15,000 kilometers of the photosphere. This is in excellent agreement with the figure obtained from observations of sunspot motions.

These measurement methods are indirect, and our view of the Sun still is limited to its visible surface. However, the combination of theory and experiment is yielding valuable information on the hidden internal structure and processes of the Sun.

COGNITIVE SCIENCE IN SCIENCE AND MATHEMATICS EDUCATION

Learning often is characterized as the transfer or delivery of knowledge from a teacher or other source to the student. In this view, learning is assumed to require only that the student pay attention to the knowledge that is being presented and copy it into his or her own memory. It is assumed that such things as discussion, practice problems, or laboratory demonstrations confirm the truth of what was learned or "fix" it firmly in memory so that it can be recalled and applied easily in the future.

However, recent research suggests that learning is a highly personalized mental activity involving a much more active struggle than the word "copy" implies.[6] It takes considerable time and mental activity for students to bring existing knowledge, skills, activities, and interests into play in confronting, interpreting, and assimilating new knowledge. Furthermore, applying the knowledge in future situations may involve active reconstruction rather than simple retrieval.[7]

This active, constructivist view of learning, in which existing knowledge and inferences play such an important part, seems to have powerful implications for the learning and teaching of science and mathematics. If learning is neither an immediate nor passive event, then the timing and nature of the interaction with pertinent materials or other resources must be critically important. If new knowledge builds on something already known and accessible to the student, then the result necessarily will be limited by the extent of the student's prior knowledge and skills; by themselves, timing and interaction will not result in mastering the new knowledge.

Conclusions such as these, from the fields of psychology, education, linguistics, philosophy, and the computer and neurological sciences, have stimulated the development of an interdisciplinary field of research called cognitive science. Such research formulates and tests theories of knowledge struc-

[4] P. A. Gilman and P. V. Foukal, "Angular Velocity Gradients in the Solar Convection Zone," *Astrophysical Journal*, vol. 229 (1979), pp. 1179-1185.

[5] F. L. Deubner, R. K. Ulrich, and E. J. Rhodes, Jr., "Solar p-Mode Oscillations as a Trace of Radial Differential Rotations," *Astronomy and Astrophysics*, vol. 72 (1979), pp. 177-185.

[6] Eleanor Duckworth, "Either We're Too Early and They Can't Learn It, or We're Too Late and They Know It Already: The Dilemma of 'Applying Piaget'," *Harvard Educational Review*, vol. 49 (August 1979), pp. 297-311.

[7] R. J. Spiro, "Remembering Information from Text: The 'State of Schema' Approach," R. C. Anderson, R. J. Spiro, and W. E. Montague (eds.), *School and the Acquisition of Knowledge* (Hillsdale, N.J.: Lawrence Erlbaum Associates, 1977).

ture and mental processes, primarily through detailed observation and modeling. An increasing number of researchers from the fields named, plus the mathematical, physical, and biological sciences, are working to understand these structures and processes in their own fields.

Early Influences and Findings

Nearly a half century ago, behavioral scientists in Europe proved the importance of prior knowledge structures and active mental processes. In 1932, F. C. Bartlett[8] reported that adults with different backgrounds comprehend unfamiliar stories differently in terms of concepts familiar to them and reconstruct the stories based on what must have been true, rather than merely recalling them from memory. In 1952, after decades of careful observations of Swiss children, J. Piaget[9] characterized learning as a continuing interplay between concepts familiar to the child and results ("new" concepts) that seem to contradict such understanding. Once activated, existing knowledge interprets and clarifies (or distorts) the new information. Conversely, the "old" knowledge may be clarified by the new.

Piaget's findings, generally confirmed in many countries including the United States, are especially important for science education because they concern the learning of important concepts, such as conservation of number, volume, and mass; as well as proportionality, logical reasoning, and the control and manipulation of variables.

Piaget's findings were quite surprising. They revealed discrepancies between what young children had been assumed to know and what those children demonstrably did know. For example, 5-year-old children who could "count" up to 30 often did not realize that if you take eight eggs out of a set of eight cups and place them in a small pile, there are still as many eggs as cups. Also surprising and important was the finding that explanation and exposure did not easily fill this "knowledge gap." If the children's knowledge structure did not include the concept of conservation of number (the number of elements in a set), it was by no means easy to teach it to them.

The role of prior knowledge structures and learning strategies was clarified in a theory of educational psychology by D. Ausubel in 1963.[10] J. Novak, another American, adopted Ausubel's theory for science learning and related it to recent theories of meaning and knowing.[11] Although the theories of Piaget and Ausubel differ in some important ways, both regard learning as the process and result of modifying existing, highly structured knowledge, and each has contributed significantly to the investigation and understanding of this topic.

Recent Observational Studies

The results of more recent research are consistent with the earlier findings and may have greater implications for formal education. For example, L. P. Steffe,[12] at the University of Georgia, has helped to reveal the complexity of the knowledge structures and skills in learning addition and subtraction. Traditionally, schools treated counting as a simple activity that is relatively unimportant in the formation of mathematical concepts. Children, therefore, often are discouraged from counting when asked to perform operations with whole numbers.

Steffe's intensive "teaching experiments" with 6- to 8-year-old children reveal a half dozen types of counting, which differ significantly in underlying knowledge structures and in the mathematical operations they permit. Further, counting starts with "rote" counting, which provides a language base, continues through "point" counting (reciting the names of the numbers in sequence while pointing to the elements of a set), and moves on to cardinal and ordinal counting in forward and backward directions. Each type of counting is necessary for the next and for a wide variety of knowledge in arithmetic. A child very well may be able to count to 30 by rote, acquire "point" counting capability, and still fail Piaget's test on eggs and cups.

The effect of existing knowledge and expectations on understanding of new concepts is striking. In the real world, we are bombarded with information and are necessarily selective in what we perceive; the rest passes us by. Our perception is to a great extent controlled by our expectations, which in turn are determined by what we already know. Knowing what cues and relationships to attend to develops over time. This accounts for a common occurrence in science and mathematics classrooms; namely, a student's inability to understand a concept even after hearing it explained patiently and

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[8] F. C. Bartlett, *Remembering: A Study in Experimental and Social Psychology* (London: Cambridge University Press, 1932).

[9] J. Piaget, *The Origins of Intelligence in Children*, trans. M. Cook (New York: International University Press, 1952).

[10] D. Ausubel, *The Psychology of Meaningful Verbal Learning* (New York: Grune and Stratton, 1963).

[11] J. Novak, *A Theory of Education* (Ithaca, N.Y.: Cornell University Press, 1977).

[12] L. P. Steffe, W. C. Spikes, and J. J. Hirstein, *Quantitative Comparisons and Class Inclusion as Readiness Variables for Learning First-Grade Arithmetical Content*, Technical Report No. 9, ERIC document No. ED 144808 (Tallahassee, Fla.: Project for the Mathematical Development of Children, 1976).

logically by an informed teacher. Teachers use perceptual cues or relationships that they know are fundamentally important to understanding the new concept. Students not understanding the importance of the cues may pay no attention to them or fail to relate them properly.

Many young children have demonstrated, in what seemed to be favorable conditions, that they cannot understand the concepts of number or quantity, or differentiate between concepts such as heat and temperature, or weight and volume. This has convinced many people that it is impossible to arrange a learning situation in which very young children can grasp such concepts. The implications of this belief for formal education in science and mathematics are obvious, and considerable effort has been expended in trying to determine when individual students are "ready" for instruction in a concept and what to do if they are not.

Other researchers, however, continue to believe that most young children can understand these concepts if they are presented in an appropriate way. At the Massachusetts Institute of Technology, S. Carey[13] is conducting extensive studies on the ability of very young children to understand the differences between related concepts such as "large" and "heavy"; and weight, volume, and density. Results from pilot studies indicate that even 3- and 4-year-old children can distinguish between "large" and "heavy" if they are permitted to become familiar with the materials and tasks used for the comparisons.

It would be important to confirm experimentally the significance of prior knowledge and context, but that would not necessarily improve education in elementary science and mathematics. Can children's attention be directed to the perceptual information necessary for understanding new concepts? If so, how can it be done to activate the knowledge already available to the children so that they can assimilate the new information? A considerable number of researchers are investigating these questions, and the results seem to be promising.

Experiments by G. Carmi at Hebrew University[14] reveal that many children as young as 5 years old can grasp perceptual cues if the most pertinent cues are made much more conspicuous than the distracting ones. Carmi's experiments involve the inability of young children to understand that pouring a liquid from a tall, thin beaker to a short, wide one does not reduce the amount of liquid. The problem, then, is to determine what cues will be most conspicuous to the child, rather than what cues seem most conspicuous to the teacher.

Carmi believes that children gradually extend their understanding of the permanence of objects, which develops very early in life, from rigid objects to flexible ones, like clothing, and then to amorphous matter like paste and liquid. He tested this theory in an experiment with 111 5- and 6-year-old children. In three different versions of a liquid conservation task, each child was asked if there were more, the same, or less liquid after transferring it. A child answering "the same" or "about the same" was judged to understand the principle that a physical substance is "conserved" even while it is being transferred.

In the standard version of the experiment, liquid is simply poured from a tall, narrow container to a short, wide one. In the second version, two sealed and transparent boxes, each taller than wide and exactly seven-eighths full of liquid, are presented to the child. One is then turned to a "lying down" position. In the third version, the water is contained loosely in a transparent plastic bag that is transported from a tall, narrow container to a short, wide one.

In all three versions, the distracting perceptual cue is the change in the level of the water in the container after it is poured, turned, or transported. The conspicuous cue, according to Carmi's theory, is the physical integrity of the water being transferred. He sought to make this "integrity" clearer in version two than in version one, and clearest of all in the third version, in which the body of water is wrapped and therefore can be transported all together, at once. The results support his theory. Only 6 children understood the conservation principle in the first version, 18 did in the second version, and 36 in the third.

Experiments such as Carey's and Carmi's indicate that it is possible to establish experimental conditions in which science and mathematics concepts seem to be perceived and understood. However, the conduct of such experiments requires considerable time on the part of a number of researchers who must observe the results.

M. B. Rowe[15] made an interesting discovery that

[13] S. Carey, "Conceptual Change in Children and Adult Scientists," (Unpublished proposal, SE 79-13278, to National Science Foundation research program, Massachusetts Institute to Technology, 1979).

[14] G. Carmi, "A Liquid-conservation Experiment," abstracts of papers presented before the National Association for Research in Science Teaching in Atlanta, Georgia, (Columbus, Ohio: ERIC Clearinghouse for Science, Mathematics, and Environmental Education, 1979), p. 99.

[15] M. B. Rowe, "Wait-time and Rewards as Instructional Variables, Their Influence on Language, Logic, and Fate-control: Part One: Wait-time," *Journal of Research on Science Teaching*, vol. 11 (1974), pp. 81-94.

relates student behavior to the amount of time that a teacher normally waits for an answer to a question. Analysis of hundreds of audio recordings of elementary science classrooms revealed a mean "wait-time" of about 1 second. When teachers are trained so that mean wait-times rise to about 3 seconds, student participation and learning improve significantly, according to analysis of nearly 1,000 audio recordings. The length of student responses increases; failure to respond decreases; the number of unsolicited but appropriate responses and speculative responses increases; and students make more statements of inference based on evidence and compare data with other students. Students also ask more questions, so that the classroom dialog changes from an inquisition to a conversation. Furthermore, the incidence of responses from "slow" students increases, and teachers expect more of such students as well.

Rowe's explanation for these results seems particularly pertinent to the teaching of science and mathematics. She believes that science is learned, just as it is discovered, through conflict between concepts. If a student's concept is wrong, it must be challenged by information (preferably evidence) that is inconsistent with the student's beliefs. The conflicts between new and old information become clearer by talking about both and arguing about what we make of our experiences, leading to the refinement and multiplication of ideas and to new questions or experiments. Rowe's evidence indicates that in classrooms with short wait-times, conversation in which students build upon each other's ideas does not develop.

Rowe's results are not too surprising. Finding even a simple piece of information in human memory takes time. For example, it takes more than 1 second, on the average, for an adult to decide if a pine tree is a plant.[16] We should, therefore, expect it to take considerably longer to retrieve and combine less familiar information about science and mathematics. A student learning new concepts will require even more time.[17]

There is also significant evidence that even after considerable formal instruction, many high school and college students have only isolated and fragmentary knowledge of science and mathematics. Much of their knowledge seems to be in terms of formulas, with little understanding of the underlying meanings and relationships represented by the formulas.

For example, about one out of six preprofessional physics students at the University of Washington consistently confused equal instantaneous speed with equal instantaneous position for pairs of balls rolling on inclined planes—in spite of having successfully completed a semester course in physics that emphasizes these concepts.[18] The students thought that the two objects had the same speed ("... just for an instant...") when one passed the other. Furthermore, nearly 70 percent of these preprofessional students consistently confused acceleration and speed. Interviews with students as they watched rolling balls, both before and after taking the course, indicated that they had not sufficiently assimilated the concepts to apply them generally to physical phenomena encountered in the real world. Once again, part of the problem appears to be that the student's attention is dominated by misleading perceptual cues. This was true even for students whose paper-and-pencil tests earned them "A's" in the course.

The failure to relate "classroom" concepts and real-world phenomena also is being investigated by J. Clement.[19] His studies involving several hundred engineering students at the University of Massachusetts reveal that many have persistent misconceptions of key qualitative concepts in physics, even after taking a semester of physics. For example, about half of the students believe that movement is necessarily accompanied by a forward force on the moving object.

Clement, with J. Lochhead and G. Monk,[20] also found that a majority of the students are unable to solve even moderately difficult algebra word problems, due in part to a serious misunderstanding of the concept of "variable" This is surprising, considering the exposure of these students to this concept in prior courses.

The problems discovered among physics students at the universities in Washington and Massachusetts are not due simply to lack of effort, carelessness, or inattention. There are consistent patterns indicating shared misconceptions that interfere with

[16] D. E. Meyer and R. W. Schvaneveldt, "Meaning, Memory Structure, and Mental Processes," C. N. Cofer (ed.), *The Structure of Human Memory* (San Francisco: W. H. Freeman, 1976).

[17] H. A. Simon, A. Newell, and K. Gilmartin, "SHORT: A Model of Short-term Memory," C. N. Cofer, (ed.), *The Structure of Human Memory* (San Francisco: W. H. Freeman, 1976).

[18] D. E. Trowbridge, and L. C. McDermott, "An Investigation of Student Understanding of the Concept of Velocity in One Dimension," *American Journal of Physics*, vol. 48 (1980), pp. 1020-28; "An Investigation of Student Understanding of the Concept of Acceleration in One Dimension," *American Journal of Physics*, vol. 49 (1981), pp. 242-250.

[19] J. Clement, "Students' Preconceptions in Introductory Mechanics," invited address to the American Association of Physics Teachers, Chicago, 1980.

[20] J. Clement, J. Lochhead, and George Monk, "Translation Difficulties in Learning Mathematics," *American Mathematical Monthly*, vol. 88 (1981), pp. 286-290.

perception and learning. Students repeatedly fail to notice evidence contradicting their misconceptions or their solutions to problems. If they perceive the contradiction, they are more likely to transform the evidence to fit their conceptions, rather than the other way around. In the presence of such misconceptions, concepts foreign to the student must displace stable concepts constructed over many years. Lecturing to a large group of students may not be the best way to promote learning of this type, particularly in science and mathematics.

Computer-Based Modeling

Considerable effort is being made to identify the nature and extent of these common misconceptions and conceptual difficulties (and assist students to overcome or avoid them) and also to understand the knowledge structures and mental processes used in learning or applying science and mathematics. An increasing number of researchers are constructing computer programs to simulate the observed behavior. Such modeling has two advantages: It forces the researchers to specify all the assumptions about the structures and processes that are involved, and it permits study of the effects of changing any or all of them.

Both of these advantages are important for cognitive research because the structures and processes are complex and perhaps unknown to the problemsolver. A computer model is one representation of a theory, in an explicit form that permits some degree of testing. Therefore, although modeling of how science is learned is in its infancy, many consider it to hold the greatest promise for acquiring useful information.

J. H. Larkin[21] at Carnegie-Mellon University is trying to learn what factors differentiate competent solvers of textbook problems in college physics—those who quickly and accurately find and apply precisely the information needed—from novices who search endlessly for information and then apply it slowly and clumsily. She also is interested in finding out how such knowledge and skill are acquired. Her approach is to interview people of varying degrees of competence while they are attempting to solve problems. The information then is analyzed, and key knowledge and strategies are inferred for each skill level. These results are used to program a computer to solve the same class of problems for each skill level.

Although the experts solved the problems in distinctly different ways from the novices, there was considerable consistency among the experts and among the novices so that the performance of either can be simulated by computer. Furthermore, Larkin found that a single program can be made more or less "skillful" by making relatively few changes in its "knowledge." The program, therefore, is able to "learn" fairly easily to become increasingly "expert" from experience in working problems. Only a handful of physics problems and problemsolvers have been studied so far, and considerable research will be needed before any general conclusions can be reached. It will be interesting to see how this approach extends to other types of problems, how mental processes such as abstraction and reorganization of knowledge can be added to the model, and how this approach can contribute to instruction in science and mathematics.

Conclusion

The evidence that learning involves modifying existing knowledge structures and mental processes seems particularly important for the learning of science and mathematics, which consist of abstract and highly interrelated concepts and which rely on complex reasoning processes. Knowledge of the structures and processes that are available to or that dominate a student, therefore, should facilitate instruction in science and mathematics.

Although the field of study is relatively new, results such as those described here are encouraging, and researchers increasingly are able to study more complex forms of learning and problemsolving. Of course, applying the findings to instruction will not be easy, but Rowe's results in prolonging wait-time indicate that application may be possible and that the effect may be quite dramatic.

INFORMATION FLOW IN BIOLOGICAL SYSTEMS

During the 1950's and 1960's, scientists dissected the fundamental unit of living systems—the cell—to determine the nature of its components and how these parts work together to transfer genetic information within the cell. It was found that the information core of the system is deoxyribonucleic acid (DNA), made up of a series of small molecules called nucleotides. A given sequence of nucleotides in the DNA is called a gene and is a repository of genetic information. Each series of three nucleotides along a DNA strand carries the code for a specific amino acid, one of the building blocks of the proteins that give a cell its structure and regulate its function.

The "messenger" in this cellular information transfer system is ribonucleic acid (RNA), a mole-

[21] J. H. Larkin, "Skill Acquisition for Solving Physics Problems," CIP No. 409 (Pittsburgh, Pa.: Department of Psychology, Carnegie-Mellon University, 1979).

cule that also is composed of consecutive, ordered, linear sequences of nucleotides, but nucleotides whose structure differs from that of DNA. The instructions from the DNA specifying which amino acid sequence is to be built (and so which protein is to be made) are brought by the RNA to the cellular machinery that synthesizes the proteins. This is the molecular mechanism of inheritance. Information encoded in the genes passed from one generation to the next specifies precisely the kind of organism that is produced.

In the 1950's, scientists also knew that information is transferred between cells, often by a chemical "messenger" called a hormone. While they knew that hormones in one part of an organism affected cells in another part, scientists did not understand how a particular hormone affected its "target." Biological information transfer between individuals also received some attention at that time, but the focus was on interactions using the senses—sight, sound, touch, smell, taste—rather than on "chemical communication."

Remarkable progress has been made since the 1950's toward unraveling the molecular details of information transfer in living systems. Our fundamental understanding of the mechanism of inheritance has mushroomed as more and more fascinating details of the structure of genes and how they are regulated have emerged. We also are beginning to understand how cells communicate with each other and how specific "signal" molecules, such as hormones, produced by one cell may cause another to respond by a change in activity. We have found that hormones thought to modulate only physiological function also affect behavior through complex cell-to-cell interactions within the brain.

Just as RNA and hormones are the chemical mediators in the transfer of information within and between cells, pheromones mediate in the transfer of information between individuals. Scientists have found that when this signal molecule is produced by one individual of a species, it may cause marked changes in the behavior of other individuals of the same species. Such information transfer also occurs between individuals of different species, even those as dissimilar as plants and animals.

As we enter the 1980's, it seems appropriate to consider some of the astounding advances made toward understanding how information flows and is processed at the molecular level in biological systems.

Newfound Aspects of the Gene

One concept that has altered greatly in the past 20 years is that of the genome, the collected genes of a given cell or organism. Although it was once thought to be a stable, almost inert, library of heritable information, we now know that the genome is quite active. While the genome is largely stable as a whole, individual genes can, in what is probably a controlled manner, move between regions of a chromosome (the structure in which they are located in higher cells), change orientation within the chromosome, and even move from one chromosome to another. The flow of the genome's information from DNA via messenger RNA (mRNA) to the protein-synthesizing machinery also is a much more complex process in higher cells than was originally thought.

Current understanding of the movement of genes in and between chromosomes was first suggested by a series of brilliant experiments done by Barbara McClintock in the 1940's using an extremely complex organism—the corn plant.[22] Because techniques were not available to follow up on her unorthodox results, McClintock's work was not really understood or appreciated until recently. Now we know that segments of genes can move about even within simple bacteria and that similar movement probably occurs in plant and animal cells, causing significant changes in their characteristics. See figure 7-3 for variations in corn caused by the movement of genes.

The bacterium, *Salmonella typhimurium*, for example, can have one of two types of flagella, the hairlike structures with which these cells propel themselves. What determines which type of flagellum a particular cell makes is the orientation of a specific gene on the chromosome. If the gene is in one position, one kind of flagellum is made. If the gene changes orientation (while remaining at the same location) the other type is made.[23]

An example of gene movement with practical significance has to do with bacterial resistance to antibiotics. Antibiotic resistance often is carried within a plasmid, a circular segment of DNA that is separate from the main chromosome of the bacterial cell, but which also may be considered to be a genome. A specific piece of the plasmid DNA can, as a unit, be incorporated into the main genome of the bacterial cell, carrying with it the gene for antibiotic resistance and other genes. Because it changes its relative position, scientists have dubbed such a plasmid segment a "transposon." Recently, the nucleotide sequence of one transposon was determined and the protein that regulates its

[22] B. McClintock, "The Origin and Behavior of Mutable Loci in Maize," *Proceedings of the U.S. National Academy of Sciences*, vol. 36 (1950), p. 344.

[23] J. Zieg et al., "Recombinational Switch for Gene Expression," *Science*, vol. 196 (1977), p. 170.

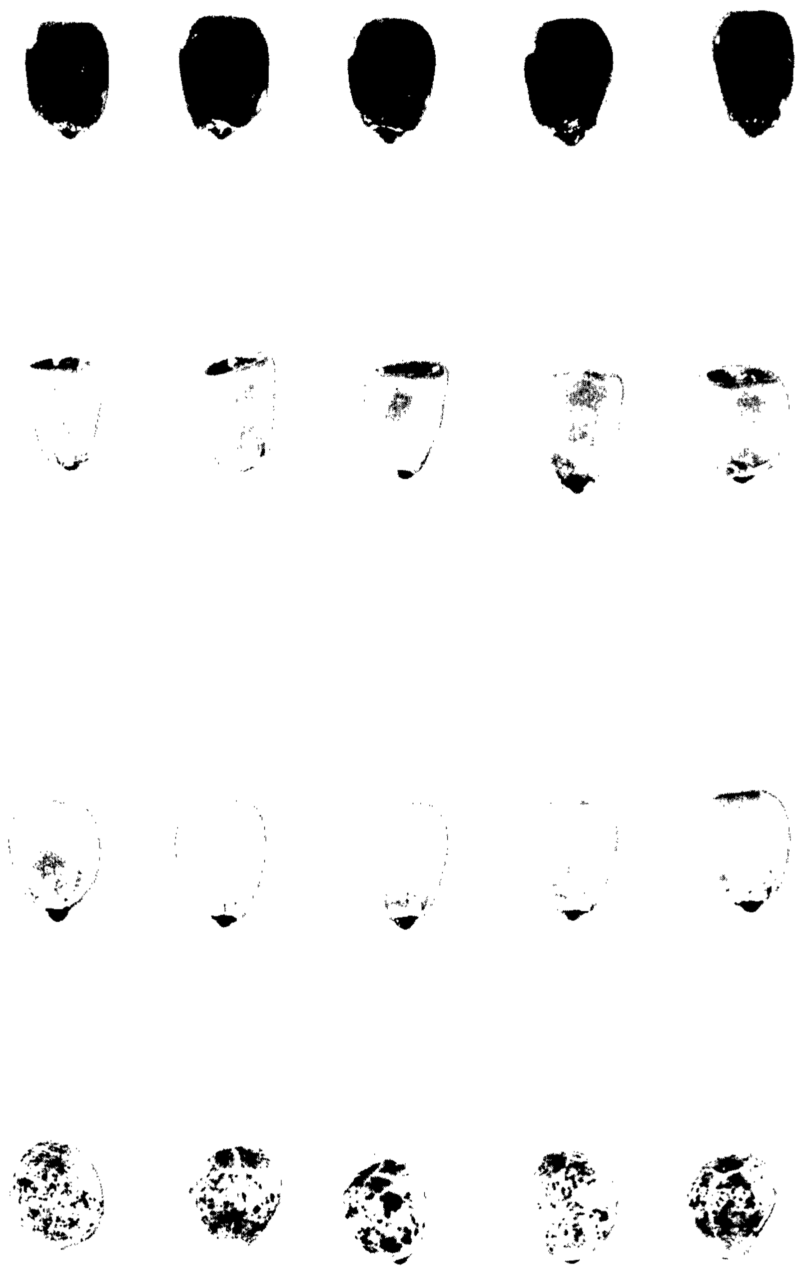

Figure 7-3 **Corn kernels showing the effect of gene movement**

movement from one genome to another was identified.[24] This makes it possible to study the molecular mechanism of transposon movement.

The mating type, or sex, of yeast cells also involves gene movement. Genes specifying mating types are expressed at a particular location on the yeast cell chromosomes. When they occur in other parts of the genome, these genes are "silent." Not until they are moved to the mating-type location on the chromosome are they activated to determine the sex of that particular yeast cell.[25]

Another instance in which gene movement is important is cell differentiation—changes during development that cause cells to acquire specific functions. For example, separate segments of DNA enable higher animals to produce a vast array of antibodies against foreign substances. These DNA segments are completely separated on the chromosome in the immature cell, but during maturation of the cell they join to produce a cell that will manufacture one of the almost infinite kinds of antibodies.[26]

Our understanding of how information stored in DNA is transferred to the cell's protein-synthesizing machinery also has been revised considerably. In bacteria, genes are specific, uninterrupted segments of DNA with start and stop signals. In some cases, "regulatory" segments of DNA, those that determine whether a gene is activated, are located at one end of the gene. When the regulatory segment gives a green light, the nucleotide sequence of the gene is copied faithfully into mRNA. The sequence of nucleotides in this messenger molecule is then translated by the protein-synthesizing apparatus into the amino acid sequences originally specified by the gene.

In animal cells, the story is not quite so simple, as was discovered in 1977 with virus-infected cells.[27] When the viral genome was copied into mRNA, this mRNA had what are now called intervening sequences or "introns." These were cut out of the linear chain of the mRNA molecule and the message rejoined before the mRNA was used to make viral proteins. Since then, a number of genes in higher cells have been found to contain these intervening sequences of nucleotides. In chickens, the gene code for an egg protein, ovalbumin, has seven such introns scattered throughout.[28] All of these intervening sequences, which together contain more DNA than the actual gene, are removed from the mRNA before it is used to make ovalbumin. Why this seemingly inefficient process occurs is still unknown.

Other differences in the organization of the genome of higher cells have been discovered. A necessary sequence for gene expression (activity) in the frog, for example, recently was shown to occur within the gene itself, rather than at one end of and outside the gene as in bacterial cells.[29] Another recent discovery is that, under certain conditions, genes are replicated without the usual production of a new chromosome, a phenomenon referred to as "gene amplification."[30] In mammalian cells grown in the presence of a specific enzyme inhibitor, the gene that codes for that enzyme dramatically increases in number. The inhibitor knocks out the normal function of the enzyme, so the cells apparently are attempting to compensate for this loss by producing more genes and, therefore, more molecules of the enzyme. Understanding the mechanism for gene amplification could have very practical significance because this process may be involved in the resistance to pesticides that insects develop after constant exposure.

Information Transfer Among Cells

That hormones produced by one kind of cell have dramatic effects on other cells in the body has been known for some time, but the complexity of this cell-cell interaction is only beginning to be unraveled.

The pituitary gland in the brain has been referred to as the "master gland" of the body because of the number of hormones it produces. When one of these polypeptide hormones encounters its "target cell," it binds to "receptor" molecules in the cell's membrane. These receptor molecules are specific for each hormone and are absent from nontarget cells, explaining why these other cells are unaffected

[24] F. Heffron et al., "The Transposon Th3 Encodes a Site-Specific Recombination System; Identification of Sites, Genes, and Actual Site of Recombination," *Cold Spring Harbor Symposium*, vol. 45 (1981), pp. 2958-2968.

[25] J. B. Hicks, J. N. Stratham, and I. Herskowitz, "The Casette Model of Mating Type Interconversion," A. J. Bukham, J. A. Shapiro, and S. L. Adyha (eds.), *DNA Insertion Elements, Plasmids and Episomes* (Cold Spring Harbor, N.Y.: Cold Spring Harbor Laboratory, 1977), pp. 457-462.

[26] M. Weigert et al., "Rearrangement of Genetic Information May Produce Immunoglobulin Diversity," *Nature*, vol. 276 (1978), p. 785.

[27] A. J. Berk and P. A. Sharp, "Structure of the Adenovirus 2 Early in RNAs," *Cell*, vol. 14 (1978), pp. 655-671.

[28] F. C. Lai et al., "The Ovalbumin Gene: Alleles Created by Mutations in the Intervening Sequences of the Natural Gene," *Cell*, vol. 16 (1979), pp. 201-211.

[29] D. F. Bogenhagen, S. Saconie, and D. P. Brown, "A Control Region in the Crator of the 55 RNA Gene Directs Specific Initiation of Transcription: II. The 3 Border of the Region," *Cell*, vol. 18 (1980), p. 27.

[30] R. T. Schimke et al., "Gene Amplifications and Drug Resistance in Cultured Marine Cells," *Science*, vol. 202 (1978), p. 1051.

by the hormone. The mechanism of binding or interaction between the hormone and its receptor molecule and the subsequent modulation of cell activity are being investigated intensively.

Binding of a hormone to its receptor causes the activation of an enzyme, adenylate cyclase. The enzyme faces inward from the cell membrane, whereas the receptor faces outward. This allows the information received on the surface of the cell to be transferred into the cell. The activation of adenylate cyclase causes an increase in the amount of cellular cyclic adenosine monophosphate (cAMP), a small molecule. One of the consequences of this increase is that other enzymes are activated by still another enzyme, called cAMP-dependent kinase, and subsequently change the cell's metabolism.[31] Because of its role in this complex system, cAMP has been referred to as the "second messenger." An example of this complex system is the regulation of testosterone production in the male. A specific hormone (luteinizing hormone), produced in the brain, is bound to testicular cells and their adenylate cyclase system activated. This activates the adenylate kinase, and testosterone production increases.

Testosterone and estrogen belong to a different class of hormones, the steroid group, and act to affect regulation of the genome itself. Whether target cells have specific membrane receptor molecules for the steroid hormones is a subject of some controversy. Such receptors do exist within the cell, however, and after they bind with the hormone, the receptor-hormone complex moves into the nucleus of the cell. In the nucleus, this complex interacts with elements of the genome, activating specific genes and resulting in the production of new proteins. In chickens, for example, estrogen causes a marked growth in the oviduct during which the gene for ovalbumin synthesis is activated.

Recently, still another dimension has been added to the mechanism of cell-cell interactions. Through totally different research, all higher cells have been found to contain an internal framework of protein referred to as the "cytoskeleton." The cytoskeleton may anchor some hormone receptors in the membrane and thus interacts with the receptors. Chemicals that affect the cytoskeleton also have been shown to affect cAMP production. Regulation of surface receptor molecules could affect a large number of cellular processes, including cell growth and antibody production.

In any event, information transfer from the surface of cells to their interior is important because normal cells cease to move and grow when they come in contact with each other. Cancer cells do not. Cell-cell contact thus appears to be an integral part of the regulatory mechanism of normal cell growth.

Cell-Cell Interactions in the Brain

Chemical mediation of information transfer between nerve cells within the brain has been recognized for some time. Molecules released by the ending of one nerve cell, for example, transmit an impulse that will either excite or inhibit another nerve cell. These molecules, relatively simple in structure, are referred to as "neurotransmitters."

Certain brain nerve cells also interact with hormone-producing cells to cause them to release their product. The hormones produced and liberated in this process are carried by the blood to their target cells. For example, vasopressin, a polypeptide hormone produced by a region of the brain called the hypothalamus, is carried to the kidneys and to the peripheral blood vessels. It causes increased water reabsorption and constriction of the blood vessels, a combination that results in an increase in blood volume and pressure. Oxytocin, another hypothalamic hormone, causes the smooth muscle of the uterus to contract and deliver the fetus at birth. It also acts on the mammary gland, causing milk "letdown."

A recent discovery is that vasopressin and oxytocin also act on specific brain cells, causing behavioral changes.[32] This indicates that in the brain these peptide hormones are acting as classical neurotransmitters. Indeed, nerve cells from the hypothalamus that terminate in the brain have been shown to contain vasopressin and, furthermore, injection of either vasopressin or oxytocin into the brain causes behavioral changes. Other peptides formed in the brain also act as neurotransmitters, causing the release of such pituitary hormones as thyrotropin, which acts on the thyroid gland, and luteinizing hormone, which causes ovulation in the female and testosterone production in the male. These discoveries have opened up a whole new area of research on the molecular basis of information transfer between brain cells.

Another extremely important discovery in this area is a new class of peptides in the brain that causes marked changes in pain sensitivity. These peptides were discovered indirectly through the

[31] P. Cohen et al., "Protein Phosphorylation and Hormone Action," *Polypeptide Hormones: Molecular and Cellular Aspects*, CIBA Foundation Symposium (Amsterdam: Elsevier, 1976), pp. 287-295.

[32] G. Holstetter, S. L. Jubb, and G. P. Kozlowski, "Vasopressin Affects the Behavior of Rats in a Positively Rewarded Discrimination Task," *Life Sciences*, vol. 21 (1977), pp. 1323-1328.

study of receptor molecules which, like their counterparts in hormone target cells, were specific in their binding properties. Rather than bind specific hormones, these receptors bind morphine, heroin, and other alkaloids of plant origin and are referred to as the "opiate receptors." Receptors that specifically bind Valium, Librium, and other synthetic drugs, including phenylcyclidine (PCP) or "angel dust," also are now known.[33] If cells have receptors to bind morphine and Valium, which relieve pain and anxiety, it seems reasonable that the brain would produce compounds with similar effects.

Some of these morphinelike peptides have been discovered and are under investigation for biological activity because of their possible significance in treating mental disorders and offering new approaches to analgesia. One such peptide, dynorphin, was recently found to be 200 times more potent than morphine in its ability to bind to receptors[34] and may, therefore, be a key factor in the brain's control of pain and in eliciting emotions.

Research on these brain peptides, now referred to as endorphins (dynorphin is a specific endorphin) and encephalins, is expanding our concepts of information transfer between cells and information flow in cells beyond the protein-synthesizing stage. Scientists recently learned, for example, that both the endorphins and encephalins, plus a well-known pituitary hormone that acts on the adrenal glands, actually are formed initially as one large protein molecule which is then cleaved into these individual peptides.[35] Vasopressin also is formed from a large precursor molecule as it moves through nerve cells.

Chemical Communication among Individuals

Just as there is chemical communication between cells within organisms, so is there between individuals. Chemical messengers called pheromones carry signals between individuals of a species. In insects, pheromones may be used to attract one or both sexes of a species or to cause antiaggregative behavior. Many of these pheromones, which can be isolated and synthesized in the laboratory, have been used in the field for insect control. For example, an attractant pheromone of the common housefly is commercially available in a bait containing sugar, pesticide, and the attractant. Because flies are attracted to the pesticide, it can be isolated from the environment, avoiding contamination of crops and waters. Pheromones also are used successfully to control bark beetles that destroy trees and lumber. The application of antiaggregative pheromones to stands of timber has diminished the destructive actions of these pests.

Chemical communication between insects can be much more complex than the above examples. The red-banded leaf roller moth, a major pest of apple orchards in the eastern United States, releases at least six different sex pheromones. Insect species that share a common environment often respond to the same pheromones, but in different mixtures. A particular sex attractant pheromone may attract one species of insect and repel another, depending on the presence of other compounds mixed with the pheromones. Research on the species specificity of pheromone mixtures may make it possible to design blends of attractant that affect specific insect pests without disrupting other species. An additional complication is the interaction of auditory and chemical signals in, for example, bark beetles. Pheromone release often is triggered by stridulation (the sound made by these insects), making the sensory interactions that determine behavior more difficult to analyze.

Following important advances in understanding the role of pheromones in insect communication, many of which resulted in technological developments important to agriculture, a large number of scientists began studying the role of chemical signals in the communication systems of mammals.[36] Chemical or odorous communication has been suggested as important in the social behavior of virtually all mammalian species, and a variety of chemical signals has been identified.[37] Some chemical signals seem to stimulate hormonal changes in the recipient—those advancing puberty for example, or those synchronizing estrous and menstrual cycles of a group of individuals.

Another kind of odorous signal seems to modify behavior. For example, many male mammals identify females by sensing their odors, which vary with the stage of the estrous or menstrual cycle and signal the male when the female is sexually receptive. Other odors identify attractive males for females. A third group, also produced by males, elicits aggressive reactions from strangers. These

[33] S. R. Zukin and R. S. Zukin, "Specific [3H] Phencycidine Binding in Rat Central Nervous System," *Proceedings of The U.S. National Academy of Sciences*, vol. 76 (1979), p. 5372.

[34] A. Goldstein et al., "Dynorphin—(1-13), An Extraordinarily Potent Opiate Peptide," *Proceedings of the U.S. National Academy of Sciences*, vol. 76, (1979), p. 6666.

[35] X. Y. Bertagna, et al., "Corticotropin, Lipotropin, and B-Endorphin Production by a Human Nonpituitary Tumor in Culture: Evidence for a Common Precursor," *Proceedings of the U.S. National Academy of Sciences*, vol. 75 (1978), p. 5160.

[36] O. E. Wilson, and W. H. Bossart, "Chemical Communication among animals," *Recent Progress in Hormone Research*, vol. 19 (1963), p. 673.

[37] R. C. Doty, *Mammalian Olfaction, Reproductive Processes and Behavior* (New York: Academic Press, 1976).

chemical communications are a part of very complex social communication networks that mammals have developed to relay to other individuals their social positions and their readiness to reproduce.[38]

Chemical Communication among Species

Chemical communication also may occur between different species, often as remotely related as plant and animal. These chemical interactions often are molded by coevolution, the reciprocal evolutionary changes that result from two or more unrelated species exerting adaptive pressures on one another. For example, the wild tropical fig fruit secretes a chemical attractant that lures a minute female fig wasp. The fig wasp not only deposits eggs in the developing fig seeds, on which the larvae feed after hatching, but also deposits the pollen that fertilizes the fig ovules.[39]

Other plants manufacture chemicals to repel insects. The coffee bean, tea leaf, and cacao bean all contain bitter alkaloid poisons—caffeine, theophylline, and theobromine, respectively—as chemical weapons. However, insects coevolving in specific interaction with a particular plant may develop ways of detoxifying these potentially lethal chemicals, perhaps by secreting an enzyme to destroy them. The insect may even perfect metabolic machinery to convert the toxin into a usable substrate. But not all the flexibility is on the side of the predator. Insect herbivores that have developed means to detoxify repellant chemicals often stimulate the plant to evolve new poisons. The southern armyworm, a caterpillar that feeds on the leaves of at least 50 varieties of plants because it can detoxify their antiherbivore substances, will not eat parsnips. This vegetable secretes xanthotoxin, a lethal chemical to which the armyworm has yet to adapt.[40]

The coevolution of chemical interactions among species can be yet more intricate. The larvae of monarch butterflies feed on the milkweed family of shrubs, vines, and weeds that exude a milky latex containing the poison curare. Monarch larvae are not affected by this substance; it remains in their bodies after metamorphosis, and the winged adults carry this chemical weapon as an antipredator device. Birds that feed on the conspicuously colored monarch butterflies become sick and soon learn to avoid eating them.[41] (See figure 7-4).

[38] G. Tombrock, "Land Mammals," T. A. Sebeok (ed.), *Animal Communication: Techniques of Study and Results of Research* (Bloomington: Indiana University Press, 1968).

[39] D. H. Jauzen, "How To Be a Fig," *Annual Review of Ecological Systems*, vol. 10 (1979), p. 13.

[40] M. Berenbaum, "Toxicity of a Furanocoumarin to Armyworms: A Case of Biosynthetic Escape from Insect Herbivores," *Science*, vol. 201 (1978), p. 532.

[41] L. P. Brower and S.C. Glalion, "Localization of Heart Poisons in the Monarch Butterfly," *Science*, vol. 188 (1975), p. 19.

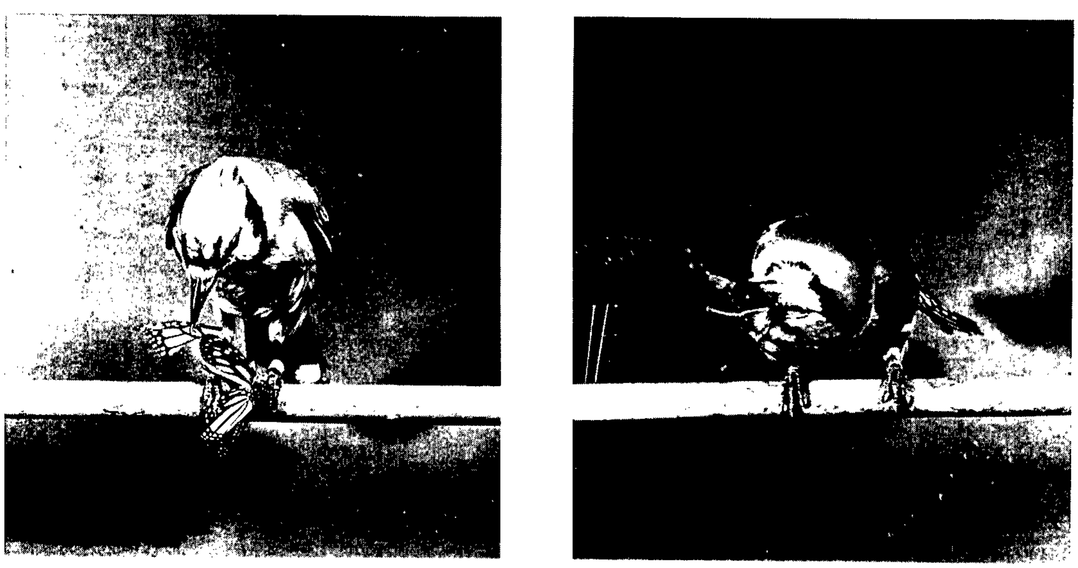

Figure 7-4 Blue jay rejecting monarch butterfly because of the curare in its body

Conclusion

For a complete understanding of chemical communication between species, we must study further the flow and control of information from DNA to proteins.

Pheromones "received" by an individual of a species are usually bound to surfaces of specific receptor cells. This surface event is relayed to the interior of the cell and ultimately causes a change in cell activity. It may result in the synthesis of new peptides, such as the peptide hormones, or in the modulation of enzyme activity. It is likely that other cells will be affected as well. Understanding the complex series of events surrounding the genome is a distant goal of biological scientists.

During the 1970's, we witnessed the practical advantages of pursuing this goal. Genetic engineering technology represents the ability to manipulate the transfer of biological information from one system to another to achieve a desirable result. This technology soon may permit the harvesting from bacterial cultures of insulin, interferon, growth hormones, and other complex molecules. Major companies in the United States and Europe are investing millions of dollars in genetic engineering. The October 22, 1979, issue of *Business Week* states that biotechnology "is the growth industry of the future," and in the August 25, 1980, issue our ability to genetically engineer plant cells is referred to as the "second Green Revolution." In the 1980's, no area of the biological sciences will be unaffected by the advances made in the 1970's in our understanding of information flow in living systems.

CATALYSTS AND CHEMICAL ENGINEERING

Basic chemical research provides an understanding of the chemical nature of substances and their reaction mechanisms, but industrial-scale chemical processes pose problems that require more extensive knowledge. Thus, on an industrial scale, where chemicals react and products are separated or purified, the rate at which these reactions proceed is not the customary predominant factor. Instead, because of the huge scale of the operation and the enormous quantities of materials involved, the rates of heat and mass transfer quite often predominate. Similarly, the extremes of temperature, pressure, and other conditions necessary for many industrial processes, and the presence of impurities in the reacting substances often require leaps beyond pure chemistry to its applied form—chemical process engineering.

The relationship between the applied science and basic chemistry is evident in research built on the fundamental knowledge of catalysts that enables us to tailor these catalysts to our needs and produce them synthetically. Catalysts are crucial substances that, even in small quantities and without undergoing changes themselves, hasten or retard an amazing array of chemical reactions. As enzymes, they regulate our body functions; as chlorophylls and auxins, they play key roles in the plant kingdom; as components of chemical processes, they help to upgrade raw materials into products such as vitamins, food, medicines, fuels, construction materials, and clothing. Catalysts increase the efficiency of industrial processes, reduce their cost, and allow the use of raw materials otherwise unacceptable because of their low purity or propensity to produce pollutants.

One economic benefit is the estimated 200 million barrels of crude oil saved each year through the process that catalytically cracks petroleum to produce gasoline. Discovered by C. J. Plank and E. Rosinski of the Mobil Research and Development Corporation, this method increases the gasoline yield to 80 percent compared to a 50-percent yield using previous methods.[42]

Why Catalysis Research?

Because a catalyst may reduce substantially the energy threshold (activation energy) required to start a chemical reaction, the search continues for more selective and efficient catalysts. A group of reacting chemicals, by following different reaction paths, may produce different sets of products. A catalyst may reduce the activation energy for one selected reaction path, speeding that particular process and producing primarily one set of products. An ideal catalyst will reduce activation energies and will conserve both energy and resources by selectively promoting the desired reaction path. The use of a catalyst also could minimize disposal or pollution problems by reducing production of all but the selected product.

In the past, the discovery and selection of new catalysts was largely an "art," relying mainly on experience, trial-and-error, or an educated guess. The need for the rational design of new catalysts became obvious with the burgeoning array of raw materials and desired products and the untold number of possible reaction paths in between. The increasing emphasis on energy and material efficiencies in

[42]C. J. Plank and E. Rosinski, "Metal-acid Beolite Catalysts: A Breakthrough in Catalytic Cracking Technology," *Chemical Engineering Progress Symposium Series*, vol. 63, No. 73 (1967), pp. 26–30; C. J. Plank and E. Rosinski, U.S. Patent 3,140,249, 1964.

processing technology also made any ad hoc approach to catalyst selection woefully inadequate.

In its place, a thorough and solid understanding of chemical reactivity at the molecular level has become the basis of a new systematic approach to catalyst design and production. In the past 2 years, the most notable achievements in catalytic synthesis relate to fuel cells, petrochemicals, and pharmaceuticals.

Fuel Cells

Fuel cells convert chemical energy directly into electrical energy by the oxidation of a fuel on the surface of an electrode. The fuel cell bypasses the thermodynamic cycle and the inherent inefficiency of the conventional heat engine, thus eliminating production of the enormous amount of rejected heat of a turbine or internal combustion engine. In addition, a fuel cell is largely nonpolluting and has few moving parts, making it quiet and comparatively maintenance free.

Electrochemical reactions, the essence of what makes a fuel cell work, usually proceed very slowly without a catalyst. So far, the most effective catalyst discovered for fuel cells is platinum, but use of this metal has drawbacks. Its cost and availability are major impediments, and fuel cells using platinum catalysts operate at less than the maximum possible voltage.

A better and less expensive catalyst for fuel cells has been developed—a big step toward making a superefficient, pollution-free electric energy source for general use—by a team of chemists from Stanford University and the California Institute of Technology.[43] These chemists found an answer to the important challenge posed by the need to achieve the swift and complete reaction of oxygen with hydrogen to produce electricity and water in a fuel cell—a reaction that releases a great deal of energy.

The Stanford group—James P. Collman, Henry Taube, and Michel Boudart—synthesized special compounds, called face-to-face porphyrins. When attached to graphite electrodes, these porphyrins catalyze the reaction of oxygen with hydrogen to form water in the acid solution of an electrochemical cell. The effectiveness of these compounds was demonstrated by Fred Anson at the California Institute of Technology. In terms of current flow and voltage, the porphyrin catalysts appear to be even more potent than the platinum catalysts now used in most fuel cells. However, neither catalyst can yet extract all the electrochemical energy available from the reduction of oxygen to water.

Some problems remain in developing the new catalysts. They are somewhat unstable, and a complicated, multistep reaction sequence is required to make them. Methods for attaching the catalyst more permanently to the graphite electrodes are needed, as are graphite materials with a greater surface area for producing higher currents. Each of these problems should be solved by further research. Prospects for success are considered particularly good because of the cooperation of academic and industrial scientists, pursued under the framework of the NSF Industry/University Cooperative Research Program.

Catalysts in Petrochemistry

Fundamental advances in catalytic synthesis also play a role in a process basic to making petrochemicals, plastics, and synthetic fibers: olefin dimerization, the union of two identical molecules in the ethylene-propylene hydrocarbon family. Metallacycles, compounds in which transition metals such as tantalum and several carbon atoms are joined in a ring structure, previously were suspected to be catalytic intermediates in the dimerization, or joining, of the complex molecules butadiene and acrylonitrile.

Recently, Richard R. Schrock of the Massachusetts Institute of Technology found that metal ions (electrically charged atoms or molecules) catalyze a selective dimerization of propylene molecules to form butene derivatives, which are starting materials for high octane fuels.[44] Robert H. Grubbs of the California Institute of Technology discovered that a metal ion catalyzes dimerization of ethylene molecules to form cyclobutane, a compound that has great promise as the basis for further research in chemical synthesis because of its highly unusual saturated 4-carbon ring arrangement. Cyclobutane, however, has proven extraordinarily difficult to synthesize by conventional means and has received relatively little research emphasis.[45]

In another petrochemical application of catalytic synthesis, both the Union Carbide Corporation and the Dow Chemical Company now have processes for manufacturing a low-density polyethylene, one of the most widely used plastics, by energy-efficient, low-pressure methods.[46] This product has been

[43] J. P. Collman et al., *Journal of Electroanalytical Chemistry*, vol. 101 (1979), pp. 117-122.

[44] S. J. McLain and R. R. Schrock, "Selective Olefin Dimerization via Tantallocyclopentane Complexes," *Journal of the American Chemical Society*, vol. 100 (1978), pp. 1315-1317.

[45] R. H., Grubbs and A. Miyasshita, "Metallocyclopentanes as Catalysts for the Linear and Cyclodimerization of Olefins," *Journal of the American Chemical Society*, vol. 100 (1978), pp. 7416-7418.

[46] F. G. Karol and H. G. Levine, U.S. Patent 4,011,382, 1979; F. G. Karol, G. L. Goeke, and B. E. Wagner, U.S. Patent 4,046,647, 1979.

made by polymerizing (joining together of many molecules) ethylene at extremely high pressures up to 1,500 atmospheres. The new processes, based on the polymerization of ethylene with other olefins such as 1-octene, use catalysts that operate at much lower pressures, typically 100 atmospheres. The Union Carbide catalyst appears to be an organometallic compound supported on a specially treated metal oxide surface.

Several recent developments in petrochemical engineering involve production of basic industrial chemicals from synthesis gas, a technical name used to describe a relatively inexpensive mixture of carbon monoxide and hydrogen that is produced from many sources, including natural gas, petroleum refining residues, and coal.

The reaction of carbon monoxide with hydrogen in synthesis gas usually is catalyzed by solutions of rhodium metal ions bound to other elements in a cluster form. The intact clusters might not be essential for catalysis, but recent work by John E. Bercaw of the California Institute of Technology suggests that intermediates containing two metal atoms bound chemically to two molecules of carbon monoxide may play a key role in the reaction.[47]

In 1976, R. L. Pruett of the Union Carbide Corporation found a way to make ethylene glycol (the basic compound in automotive antifreeze) from synthesis gas.[48] Recent patents based on the research of R. C. Williamson and T. P. Kobylinski of the Gulf Oil Company indicate that metals such as ruthenium and iridium, in combination with the organic molecule pyridine, produce much higher yields of ethylene glycol from synthesis gas than do the rhodium compounds.[49] Soluble ruthenium and cobalt catalysts also bring about the reaction of methanol with synthesis gas to produce ethyl alcohol. Similar reactions catalyzed by rhodium complexes lead to the production of vinyl acetate, a basic industrial chemical made from petroleum.

Coal-Based Synthesis

Abundant domestic coal resources have stimulated research to develop catalysts, separation techniques, and solids-handling methods for converting coal into useful chemicals. For example, in one such process, live steam is passed through a bed of crushed coal to form carbon monoxide and hydrogen (synthesis gas). This mixture is providing important building blocks for the synthesis of industrial chemicals. Depending on the relative concentrations of carbon monoxide and hydrogen, pressures, temperatures, and the catalysts being used, an almost infinite variety of chemicals can be synthesized.

In the Fischer-Tropsch process for producing synthetic fuels from synthesis gas (used by Germany in World War II when its petroleum supplies were cut off), the support material, on which the active catalyst is impregnated, affects the selectivity of the reaction to a greater extent than previously believed. Unconventional supports, such as titania and carbon, can be designed to control this selectivity. The mechanism and factors responsible for these effects still are being studied, and the limits of the technique are not yet known. Prototype systems can produce methane, paraffins, olefins, or aromatics, providing hope that in the future coal conversion plants can be more efficient and produce a higher grade of products.

In January 1980, the Tennessee Eastman Company announced plans to construct a major facility to synthesize acetic anhydride (also a major industrial chemical) from coal via carbon monoxide and hydrogen. Such a plant will be a major engineering achievement, as it will mark the first time that the U.S. chemical industry has turned away, on a major scale, from using petroleum or natural gas as a feedstock. The basic chemical pathway for the four-step process has been known for some time, but its large-scale implementation was hampered by engineering problems, especially in the gasification step. One of the company's engineering innovations will be to juxtapose a jet of coal slurry with a jet of oxygen to provide the energy needed for oxidation.[50] This is one example of industrial technology requiring much more than a mere modification of laboratory procedures.

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[47] P. T. Wolczanski, R. S. Threlkel, and J. E. Bercaw, "Reduction of Coordinated Carbon Monoxide to 'Zirconoxy' Carbenes with Permethylzirconocene Dihydride," *Journal of the American Chemical Society*, vol. 101 (1979), p. 218.

[48] R. L. Pruett and W. E. Walker, U.S. Patent 3,957,857, 1976.

[49] R. C. Williamson and T. P. Kobylinski, U.S. Patent 4,170,605 and U.S. Patent 4,170,606.

[50] This part of the process in based on Texaco technology. According to Nulit Madinger, manager of the Contracts Division of Texaco Development Corporation, Tennessee Eastman is licensed to use all of Texaco's gasification technology. The number of patents runs "over one page," and it is difficult to pinpoint which patent(s) Tennessee Eastman has used. The following are two references to Texaco's gasification technology:

W. G., Schlinger, J. Fable and R. Specks, "Coal Gasification for Manufacture of Hydrogen," paper read at the American Chemical Society and Chemical Society of Japan Joint Chemical Congress, Honolulu, Hawaii, April 1-6, 1979 (Abstract No. INDE-236 to be published in *ACS Spring Symposium No. 116, Production and Marketing of Hydrogen, Current and Future*).

A. M. Robin and W. G. Schlinger, "Gasification of Coal Liquefaction Residues," *Proceedings of the 13th Intersociety Energy Conversion Engineering Conference*, conference held at San Diego, California, August 20-25, 1978, by the Society of Automotive Engineers, vol. 1, pp. 431-437.

Catalytic Membrane Reactors

Another example of engineering innovations involving catalysis is the integration of membrane technology into catalytic and enzymatic reactors. Membrane technology is a novel and energy-efficient way to separate and purify chemical substances. Conventional separation processes now account for 70 to 80 percent of the capital cost and energy consumption in a typical chemical process plant. Normally the separation steps, whether for final product purification or for the separation of intermediates, take place in special vessels apart from the reaction vessels. The introduction of membranes into catalytic and enzymatic reactors signals a new generation of compact and energy-efficient reactor systems.

A team led by John Quinn of the University of Pennsylvania and Stephen Matson of the General Electric Company has built a prototype reactor using a porous cellulose membrane to which an enzyme has been bound.[51] The enzyme catalyzes a chemical reaction in which water is added to a derivative of an amino acid to produce that amino acid and an alcohol. This cellulose membrane is covered by another membrane whose pores are filled with decanol (a higher molecular weight alcohol). The outer decanol-filled membrane allows the derivative to pass through and react with water when contact is made with the enzyme in the cellulose membrane. However, the resulting product is prevented from passing back into the feed stream.

Pharmaceutical Chemistry Catalysis

Nature builds complicated molecules from simple ones easily and quickly by using enzymes, which are proteins formed in living cells. Enzymes are efficient catalysts that speed up specific chemical reactions, but they are so complex that it is impractical to synthesize them in many cases. Moreover, they do not catalyze many of the types of chemical reactions that may be desired.

Barry M. Trost of the University of Wisconsin-Madison recently took the first steps toward making by chemical means the antitumor agent, vinblastine, and erythromycin, an antibiotic widely used in the treatment of bacterial diseases.[52] A simple metallic catalyst is used to manipulate molecules to form new molecules that otherwise could not be made easily in a laboratory.

[51] J. A. Quinn and S. L. Matson, "Product Separation and Enrichment in Membrane Reactors," paper read at the American Institute of Chemical Engineers 72nd Annual Meeting, 1979, Preprint No. 30d.

[52] B. M. Trost, "Pure and Applied Chemistry," *Proceedings*, First International Kyoto Conference on New Aspects of Organic Chemistry, vol. 51 (1978), p. 787, (in press).

Trost's approach, in effect, provides a simple catalyst that selectively directs certain kinds of organic reactions similar to those catalyzed by enzymes in the living cell. But he uses a special form of palladium, a metal, to change the normal reaction of organic compounds. The basic framework of many important compounds is created by the formation of chemical bonds between two carbon atoms, a process called alkylation. The addition of a palladium catalyst not only allows certain atoms to unite, but it unites them much more efficiently than other alkylating agents can. When palladium is used to control these organic reactions, the normal rules for chemical reactivity do not apply, and a new set must be developed. Applying these new rules to practical problems and discovering yet other methods for controlling reactions present exciting challenges for the future.

Metal Cluster Catalysts

Metal clusters provide a bridge between homogeneous (all in one phase, such as a solution) and heterogeneous (in more than one phase, such as a solid and a fluid) catalysis. These clusters generally are soluble compounds whose structures can be studied by X-ray crystallography and other physical techniques. They contain metal-metal bonds and the beginnings of the metal-metal interactions characteristic of metallic solids, and thus yield information about the chemistry that occurs on the surfaces of metal catalysts.

Among the most exotic clusters is one synthesized recently by L. F. Dahl of the University of Wisconsin in collaboration with the late Paolo Chini of the University of Milan[53] (figure 7-5). The cluster contains 38 platinum atoms and 44 carbon monoxide groups (carbonyl ligands), but despite its size, it is soluble in some simple organic solvents and displays the cubic close-packed structure found in platinum. Thus, it will be an excellent model for studying heterogeneous catalysis and may serve as a starting material for entirely new catalysts of industrial importance.

COMMUNICATIONS AND ELECTRONICS

Research that began early in this century set the framework for two scientific breakthroughs crucial to the significant advances being made today in communications and related electronics. Continuous efforts by a number of people led to these two

[53] L. F. Dahl, "The Relationship between Metal Cluster Compounds, Surface Science and Catalysis," paper read at the U.S.-France Cooperative Science Seminar, Asilomar Conference Grounds, Pacific Grove, California, November 18-21, 1979.

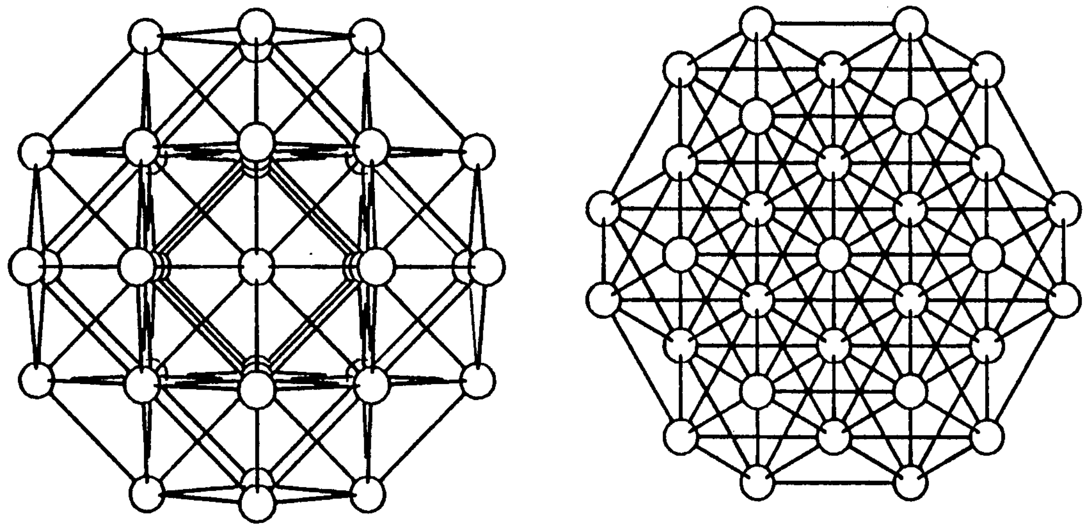


Figure 7-5 **Two Views of Cluster Containing 38 Platinum Atoms and 44 Carbon Monoxide Groups**

key inventions which have fostered whole new areas of engineering research and provided the foundation for innovative, manmade communication systems. The two breakthroughs are:

- The invention in 1948 of the transistor, based on early research in solid state physics, spawned an enormous solid state technology that has led to an era in which solid state devices have become an integral part of life.[54,55]
- The invention in 1960 of the laser, based on the fundamentals of quantum electronics, stimulated interest in developing communication systems using highly directional beams of coherent light. The laser principle, originally developed for microwaves, was extended to optical wavelengths in 1958, and in 1960 the first operational laser was produced.[56,57]

Since the invention of the transistor, the production and use of electronic devices has grown phenomenally while their costs have diminished rapidly. Although inflation has marked the national and world economies, the cost of electronic systems actually has decreased.[58] In 1955, black and white television sets sold for $350. A comparable set now costs barely $100. An IBM 1620 general purpose computer cost about $60,000, 25 years ago. Today a microprocessor with equivalent computational power sells for a few hundred dollars. An individual now can own a more powerful computation system than a large company did a quarter century ago.[59]

Progress in communications has been just as dramatic. Today, communication systems play a near revolutionary role in our society, with new developments promising even greater impact in the future. Once sophisticated methods of communication are coupled with extremely fast computation, for example, information will be transmitted far more efficiently. A number of technical advances are responsible for this progress. Thus, communications satellites, which have been very successful as relays, make possible the worldwide transmission of information via television. Extensive electronic communication systems that can

[54] W. Shockley, *Electrons and Holes in Semiconductors* (New York: Van Nostrand, 1950).

[55] J. Bardeen, "Surface States and Rectification at Metal-semiconductor Contact," *Physical Review*, vol. 71 (1947), pp. 717-722.

[56] A. L. Schawlow and C.H. Townes, "Infrared and Optical Masers," *Physical Review*, vol. 112, (December 1958), pp. 1940-1949.

[57] T. H. Maiman, "Stimulated Optical Radiation in Ruby Masers," *Nature*, vol. 187 (August 1960), pp. 493-494.

[58] R. N. Noyce, "Large-scale Integration: What Is Yet to Come?" *Science*, vol. 195 (1977), pp. 1102-1106.

[59] J. G. Linvill and C. L. Hogan, "Intellectual and Economic Fuel for the Electronics Revolution," *Science*, vol. 195 (1977), pp. 1107-1113.

simultaneously transmit voice, data, and video information are in the planning and design stage.

Electronics research is fundamental to the future growth of communications. Tens of thousands of transistors now can be placed on a single chip of silicon only about 10 millimeters wide. Soon a single chip will hold a million transistors. This high density of components, which provides great flexibility in the creation of new communication systems, is referred to as very large-scale integrated (VLSI) electronic circuitry.

A second emerging development is the use of optical frequencies for communications. The capacity of any form of electromagnetic radiation to carry signals (information) depends on its frequency. The higher the frequency, the more information the electromagnetic radiation can carry. With their relatively high frequencies, for example, visible and near-infrared light waves have an inherently high capacity for carrying information, an attribute which researchers have sought to exploit.

The discovery of the laser led to an earnest search for optical communication system components. Progress was first hampered by the lack of a practical way to transmit the light. The atmosphere, seemingly a natural enough medium, is unsatisfactory because light waves passing through it are attenuated by turbulence and scattering.

Before 1965, optical fibers, long glass rods with hair-like circular dimensions, were not considered a serious contender as the much-sought medium for light waves because transmission losses were too great. However, in 1965 the results of theoretical studies of materials and wave propagation,[60] led to the manufacture of efficient optical fibers permitting their use in communication systems.

Use of glass fiber guides to transmit optical energy became feasible in the early 1970's when the light losses in fibers were reduced by a factor of a thousand by purifying (no simple task) silica used in manufacturing the silica glass.[61] The light energy is guided by a structure consisting of a core surrounded by a cladding that optically confines the lightwaves to the core.

There are two basic types of optical fibers (figure 7-6). The large core or fiber permits the coexistence and propagation of up to 1,000 frequencies with considerable interference among them. On the other hand, the extremely small core fiber allows one frequency of the optical wave to be propagated, thus eliminating interference. Because of these propagation characteristics, the small core fiber has a much higher information-carrying capacity. Nevertheless, large optical fibers now are in experimental use in a number of telephone systems around the world and in devices connecting computers. Future fiber optic communication operations will use small core fibers and will be designed so that each complete system is based on a single material (or substrate), like that of integrated electronic circuits.

Integrated optical circuitry depends on two findings made in 1969. The first showed that light can be confined in a specific plane by "sandwiching" it (the light itself) between two layers of material (thin film) with slightly different refractive indexes. The second provided a prism coupling to direct the light into the plane. Together, they make it possible to guide light in a plane and to achieve such important communications functions as switching, mixing, modulation, and detection within the substrate or film.[62,63,64]

In the decade after discovery of the concept of optical integration, research concentrated on developing ultrasmall optical devices based on precise guiding of laser light. More recently, emphasis has shifted to placing the devices into integrated optical circuits. Amnon Yariv of the California Institute of Technology has successfully integrated a laser and an electronic modulator which varies the amplitude of the laser output, on the same material system, the semiconductor gallium arsenide.[65]

In its simplest form, a communication system consists of a transmitter, a transmission medium, and a receiver. As has been evident for some time, information can be effectively communicated at radio frequencies by varying either the amplitude or the frequency of the transmitted signal according to the information to be transmitted. This is as true for optical communications as it is for radio communications, but until recently there was no known way to vary the laser frequency. Recently, C. L. Tang and J. M. Ballantyne of Cornell University were able to demonstrate for the first time

[60] K. C. Kao and G. A. Hockham, "Dielectric-fibre Surface Waveguides for Optical Frequencies," *Proceedings of the Institute of Electrical and Electronics Engineers*, vol. 13 (1966), pp. 1151-1158.

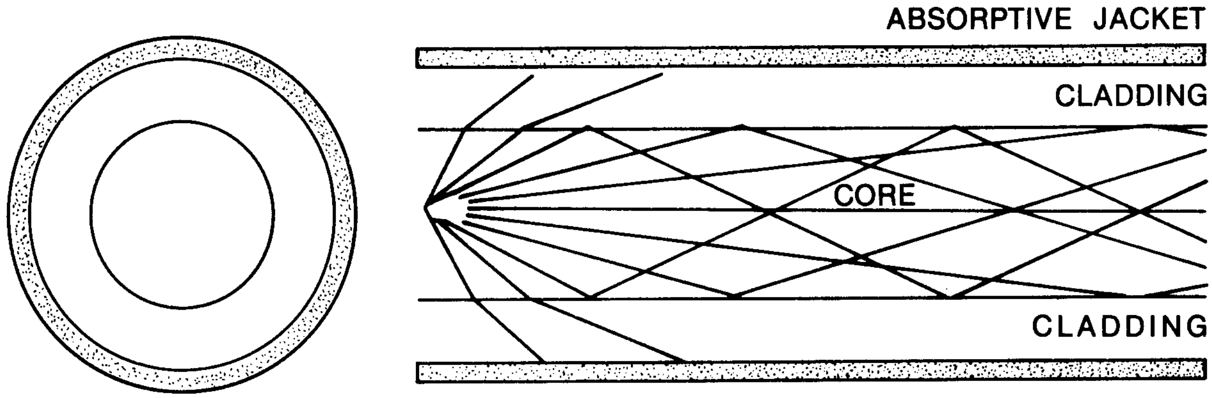
[61] F. P. Kapron, D. B. Keck, and R. D. Maurer, *Applied Physics Letters*, vol. 17 (1970), pp. 423-425.

[62] S. E. Miller, "Integrated Optics: An Introduction," *Bell Systems Technical Journal*, vol. 48 (September 1969), pp. 2059-2069.

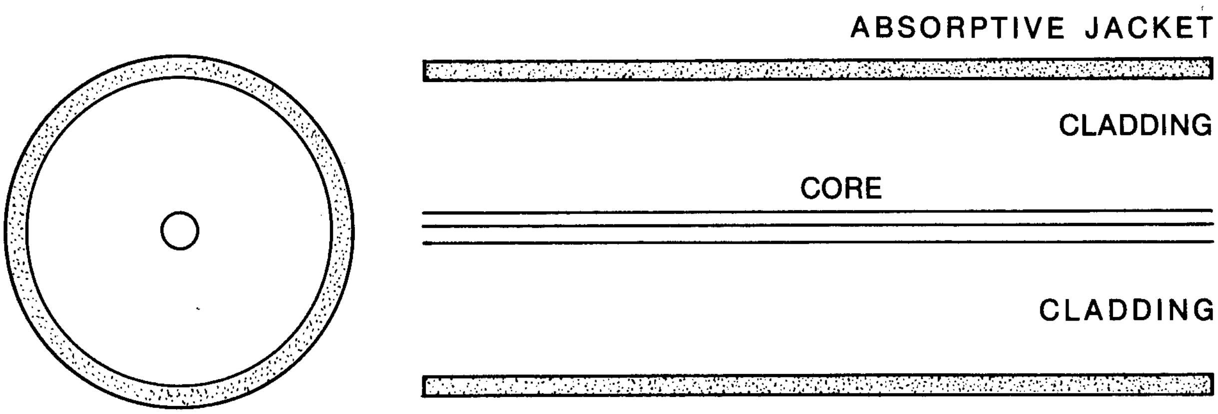
[63] P. K. Tien, "Integrated Optics and New Wave Phenomena in Optical Waveguides," *Reviews of Modern Physics*, vol. 49 (April 1979), pp. 361-420.

[64] J. H. Harris and R. Shubert, "Optimum Power Transfer from Beam to Surface Wave," paper read at the International Union of Radio Science (URSI), Washington, D.C. (April 1969) p. 71.

[65] M. I. Yust et al., "Monolithic Integration of Semiconductor Lasers and Active Devices," *Proceedings of the NSF Grantee-User Meeting on Optical Communications Systems*, (June 1979), pp. 165-169.



Large-core, solid-clad multimode fiber may be slightly wider than a human hair. Its central core is 50-70 microns (thousandths of a millimeter) in diameter. The outer cladding has an index of refraction somewhat lower than the core. As a result, light rays are trapped in the core by reflection from cladding. A zigzag path slows arrival of some rays.



Single-mode fiber has a core diameter so small—a few microns—that only one light ray can travel along its axis. Since there are no other light rays to create interference, single-mode fibers can carry more information. However, their small size makes handling very difficult, and a laser's narrow beam of light is required as a light source.

Figure 7-6 **Basic types of optical fibers**

frequency modulation (FM) of a semiconductor laser over a large frequency range.[66]

The electronically tuned laser system can be contained in a cylindrical space about 20 centimeters long and 3 centimeters in diameter. Although very large compared to a conventional semiconductor laser, the system is extremely small compared to other electronically tunable lasers. Tang believes that this tunable laser can be reduced to a form for use in integrated optical circuits, because the essential parts of the tuner portion of the laser already exist in such form, although they work only marginally well.

The feasibility of using such an electronically tunable laser source in a simple FM optical analog

[66] C. L. Tang and J. M. Ballantyne, "Nonlinear and Active Optical Devices for Optical Communications," *Proceedings of the NSF Grantee-User Meeting on Optical Communications Systems*, (June 1969), pp. 66-69.

system has been demonstrated. As in FM radio communications, an FM optical system using the atmosphere for transmission can be made relatively insensitive to large amplitude variations introduced in the transmission. An FM digital optical communication system that uses two different frequencies to transmit a "pulse" or "no pulse" (binary one and zero) has been devised and experimentally operated.

The marriage of integrated electronics and optical communications is likely to have a profound effect on the fundamental character of society. Very large-scale integration in electronics, coupled with high-capacity optical fiber communication systems, will affect how much energy we use, our mode of travel, and the lives we lead. Sophisticated communication and computation capability in the office and at home can promote new achievements in education, entertainment, productivity, and can contribute to a higher quality of life.

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Appendix I
Statistical Tables

Appendix table 1-1. Scientists and engineers[1] engaged in R & D per labor force population, by country: 1965-80

Country	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
	Scientists and engineers[1] engaged in R & D per 10,000 labor force population															
France	21.0	23.3	25.3	26.4	27.2	27.3	27.8	28.1	28.4	28.8	29.3	29.9	30.3	NA	NA	NA
West Germany	22.7	22.4	24.9	26.2	28.4	30.9	33.8	36.0	37.8	39.1	41.0	41.7	44.3	NA	NA	NA
Japan	24.6	26.4	27.8	31.2	30.8	33.4	37.5	38.1	42.5	44.9	47.9	48.4	49.9	49.4	NA	NA
United Kingdom	19.6	NA	NA	20.8	NA	NA	NA	30.4	NA	NA	31.3	NA	NA	NA	NA	NA
United States	64.1	66.1	66.1	66.9	65.9	63.6	60.6	58.2	56.9	56.3	56.4	56.7	57.7	58.3	59.2	60.4
U.S.S.R. (lowest)	44.8	47.1	50.7	53.5	56.5	58.4	63.0	66.5	73.5	74.5	78.2	80.7	81.3	82.9	84.2	85.9
U.S.S.R. (highest)	48.2	51.4	55.3	58.8	62.1	64.2	69.1	73.2	81.5	82.9	87.5	90.9	91.5	93.3	94.9	96.7
	Scientists and engineers engaged in R & D (in thousands)															
France	42.8	47.9	52.4	54.7	57.2	58.5	60.1	61.2	62.7	64.1	65.3	67.0	68.0	NA	NA	NA
West Germany	61.0	60.0	64.5	68.0	74.9	82.5	90.2	96.0	101.0	102.5	103.9	104.5	111.0	NA	NA	NA
Japan	117.6	128.9	138.7	157.6	157.1	172.0	194.3	198.1	226.6	238.2	255.2	260.2	272.0	273.1	NA	NA
United Kingdom	49.9	NA	NA	52.8	NA	NA	NA	76.7	NA	NA	80.7	NA	NA	NA	NA	NA
United States	494.5	521.1	534.4	550.4	555.2	546.5	526.4	518.3	518.4	525.1	534.9	549.2	573.9	597.3	621.2	645.0
U.S.S.R. (lowest)	521.8	556.5	607.8	650.8	698.8	733.3	804.2	862.5	966.7	995.8	1,061.2	1,113.7	1,140.0	1,179.0	1,214.0	1,254.0
U.S.S.R. (highest)	561.4	607.6	862.6	751.2	767.5	806.9	881.8	950.1	1,072.1	1,108.0	1,187.6	1,254.5	1,282.0	1,327.0	1,368.0	1,412.0
	Total labor force (in thousands)															
France	20,381	20,522	20,676	20,744	20,996	21,465	21,638	21,817	22,083	22,282	22,310	22,440	22,468	NA	NA	NA
West Germany	26,887	26,801	25,950	25,968	26,356	26,668	26,725	26,655	26,712	26,215	25,323	25,088	26,044	25,209	NA	NA
Japan	47,870	48,910	49,830	50,610	50,980	51,530	51,860	51,940	53,260	53,100	53,230	53,780	54,520	55,320	NA	NA
United Kingdom	25,498	25,632	25,490	25,378	25,375	25,308	25,122	25,195	25,546	2[illegible],602	25,798	26,098	26,324	26,360	NA	NA
United States	77,178	78,893	80,793	82,272	84,240	85,903	86,929	88,991	91,040	93,240	94,793	96,917	99,534	102,537	104,996	106,821
U.S.S.R.	116, 494	118,138	119,893	121,716	123,584	125,612	127,672	129,722	131,610	133,600	135,767	137,987	140,140	142,214	144,201	146,068

[1] Includes all scientists and engineers engaged in R & D on a full-time-equivalent basis (except for Japan whose data include persons primarily employed in R & D and the United Kingdom whose data include only the Government and industry sectors).

NA = Not available

NOTE: Estimates are shown for most countries for latest years and for the United States for 1966 and 1967. A range has been provided for the U.S.S.R. because of the difficulties inherent in comparing Soviet scientific personnel data.

SOURCES: Organisation for Economic Co-operation and Development, *Labor Force Statistics, 1965-1976* (Paris: OECD, 1978), p. 23; Quarterly Supplement; Department of Labor, *Employment and Earnings,* February 1981, p. 19.

France: Délégation Générale à la Recherche Scientifique et Technique, unpublished statistics.
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U.S.S.R.: Dr. Robert W. Campbell, *Reference Source on USSR R & D Statistics, 1950-1978,* 1978; Steven Rapawy, *Estimates and Projections of the Labor Force and Civilian Employment in the U.S.S.R., 1950 to 1990,* Foreign Economic Report No. 10, U.S. Department of Commerce, 1976, p. 19; Robert W. Campbell, *Soviet R & D Statistics 1977-1980,* National Science Foundation, 1981.

See figure 1-1.

Appendix table 1-2. U. S. bachelors degrees and U.S.S.R. diplomas conferred by higher educational institutions, by major field of study: 1960-1979

Field of study	1960		1965		1970		1975		1976		1977		1979	
	U.S.	U.S.S.R.	U.S.	U.S.S.R.	U.S.	U.S.S.R.	U.S.	U.S.S.R.	U.S.	U.S.S.R.	U.S.	U.S.S.R.	U.S.	U.S.S.R.
	Number (in thousands)													
All fields total	394.9	343.3	538.9	403.9	833.3	630.8	987.9	713.4	997.5	734.6	993.0	751.9	1000.6	790.0
Science and Engineering total	89.4	162.5	109.3	211.8	147.6	328.5	161.4	370.9	164.4	383.4	168.7	397.9	179.7	416.9
Physical and life sciences and mathematics[1]	45.3	25.1	65.7	25.6	91.4	39.7	96.5	44.9	98.2	46.3	97.5	47.8	93.6	49.8
Engineering	37.8	102.9	36.8	152.3	44.8	230.5	47.3	272.1	46.7	280.4	49.7	291.4	62.8	306.8
Agriculture	6.3	34.5	6.8	33.9	11.4	58.3	17.6	53.9	19.5	56.7	21.5	58.7	23.2	60.3
Non-S/E fields	305.5	180.8	429.6	192.1	685.7	302.3	826.5	342.5	833.1	351.2	824.3	354.0	820.9	373.1
	As a percent of the 22/23 year old population[2]													
All fields total	17.6	7.8	18.1	13.3	23.9	19.3	26.0	16.4	25.6	17.1	23.5	16.8	24.1	16.4
Science and engineering total	4.0	3.7	3.7	7.0	4.2	10.1	4.3	8.5	4.2	8.9	4.3	8.9	4.3	8.7
Physical and life sciences and mathematics[1]	2.0	.6	2.2	.8	2.6	1.2	2.5	1.0	2.5	1.1	2.5	1.1	2.3	1.0
Engineering	1.7	2.3	1.2	5.0	1.3	7.1	1.2	6.2	1.2	6.5	1.3	6.5	1.5	6.4
Agriculture	.3	.8	.2	1.1	.3	1.8	.5	1.2	.5	1.3	.5	1.3	0.6	1.3
Non-S/E fields	13.6	4.1	14.4	6.3	19.6	9.3	21.8	7.9	21.4	8.2	20.8	7.9	19.8	7.8

[1]Figures for the U.S.S.R. are estimates made by SRI International to approximate the U. S. definitions.
[2]Based on 22-year-olds for the U. S. and on 23-year-olds for the U.S.S.R., because of the differences in average length of years required to graduate from higher education.

SOURCES: *Earned Degrees Conferred,* National Center for Education Statistics; *National Economy of the U.S.S.R. in 1970 and 1979;* U.S.S.R. Population Data from Foreign Demographic Analysis Division, U. S. Department of Commerce, U. S. population data from Population Division, U. S. Bureau of Census; Catherine P. Ailes and Francis W. Rushing, *Training and Utilization of Scientists and Engineers: U. S. and U.S.S.R.* (Washington DC: SRI International, 1980), pp. 75-76.

See figure 1-2.

Appendix table 1-3. National expenditures for performance of R & D as a percent of gross national product (GNP) by country: 1961-81

Year	France	West Germany	Japan	United Kingdom	United States	U.S.S.R.
	Ratio of R & D expenditures to Gross National Product[1]					
1961	1.38	NA	1.39	2.46	2.73	NA
1962	1.46	1.25	1.47	NA	2.73	2.64
1963	1.55	1.41	1.44	NA	2.87	2.80
1964	1.81	1.57	1.48	2.29	2.96	2.87
1965	2.01	1.73	1.54	NA	2.89	2.85
1966	2.06	1.81	1.48	2.32	2.88	2.88
1967	2.13	1.97	1.53	2.30	2.89	2.91
1968	2.08	1.97	1.61	2.27	2.82	NA
1969	1.94	2.05	1.65	2.22	2.71	3.03
1970	1.91	2.18	1.79	NA	2.63	3.23
1971	1.90	2.38	1.84	NA	2.48	3.29
1972	1.86	2.33	1.85	2.06	2.40	3.58
1973	1.76	2.22	1.89	NA	2.32	3.66
1974	1.79	2.26	1.95	NA	2.29	3.64
1975	1.80	2.38	1.94	2.05	2.27	3.69
1976	1.77	2.29	1.93	NA	2.26	3.55
1977	1.76	2.32	1.92	NA	2.24	3.46
1978	1.76	2.37	1.93	2.11	2.23	3.47
1979 (prelim.)	NA	2.36	NA	NA	2.25	3.44
1980 (est.) ..	NA	NA	NA	NA	2.33	3.47
1981 (est.) ..	NA	NA	NA	NA	2.37	NA
	R & D expenditures (national currency in billions)[2]					
1961	4.5	NA	275.5	.68	14.3	NA
1962	5.4	4.5	319.3	NA	15.4	5.2
1963	6.4	5.4	368.3	NA	17.1	5.8
1964	8.3	6.6	438.1	.77	18.9	6.4
1965	9.8	7.9	508.6	NA	20.0	6.9
1966	11.0	8.8	576.6	.89	21.8	7.5
1967	12.2	9.7	702.5	.93	23.1	8.2
1968	13.1	10.6	877.5	.99	24.6	9.0
1969	14.2	12.2	1,064.7	1.05	25.6	10.0
1970	15.0	14.8	1,355.5	NA	26.1	11.7
1971	16.6	18.0	1,532.4	NA	26.7	13.0
1972	18.3	19.2	1,791.9	1.31	28.4	14.4
1973	19.8	20.5	2,215.8	NA	30.7	15.7
1974	23.0	22.3	2,716.0	NA	32.8	16.5
1975	26.2	24.6	2,974.6	2.15	35.2	17.4
1976	29.8	25.7	3,320.7	NA	38.9	17.7
1977	33.2	27.7	3,651.3	NA	42.9	18.3
1978	37.5	30.5	4,045.9	3.44	48.0	19.3
1979 (prelim.)	NA	32.9	NA	NA	54.2	20.2
1980 (est.) ..	NA	NA	NA	NA	61.1	21.3
1981 (est.) ..	NA	NA	NA	NA	69.1	NA

(continued)

Table 1-3. (Continued)

Year	France	West Germany	Japan	United Kingdom	United States	U.S.S.R.
	Gross National Product (national currency in billions)					
1961	328.4	333.0	19,852.8	27.5	524.6	NA
1962	367.2	360.5	21,659.5	28.9	565.0	197.2
1963	412.0	382.1	25,592.1	30.8	596.7	206.8
1964	456.7	419.6	29,661.9	33.5	637.7	223.2
1965	489.8	458.2	32,981.6	36.0	691.1	242.1
1966	532.0	487.4	38,872.8	38.4	756.0	260.1
1967	574.8	493.7	45,896.8	40.5	799.6	282.0
1968	630.0	535.2	54,576.8	43.8	873.4	NA
1969	734.0	597.7	64,513.6	47.1	944.0	329.6
1970	783.6	679.0	75,523.9	51.6	992.7	362.6
1971	873.1	756.0	83,166.0	57.8	1,077.6	394.8
1972	961.3	827.2	96,883.1	63.8	1,185.9	401.8
1973	1,121.3	920.1	117,257.9	74.1	1,326.4	429.4
1974	1,284.4	986.9	139,219.3	84.0	1,434.2	453.1
1975	1,455.2	1,034.9	153,126.3	104.7	1,549.2	471.8
1976	1,677.8	1,125.0	171,735.6	124.6	1,718.0	498.6
1977	1,881.8	1,197.2	190,426.3	142.3	1,918.0	528.8
1978	2,135.1	1,287.5	209,248.2	162.5	2,156.1	556.8
1979 (prelim.)	NA	1,393.8	NA	NA	2,413.9	587.9
1980 (est.) ..	NA	NA	NA	NA	2,626.1	614.5
1981 (est.) ..	NA	NA	NA	NA	2,920.0	NA

[1] Calculated from unrounded figures.
[2] Gross expenditures for performance of R & D including associated capital expenditures except for the United States where total capital expenditure data are not available. U. S. estimates for the period 1972-80 show that the inclusion of capital expenditures would have an impact of less than one tenth of one percent on the R & D/GNP ratio.

NA = not available.

NOTE: The latest data may be preliminary or estimates.

SOURCES: International Monetary Fund, *International Financial Statistics*, vol. 30 (May 1977); vol. 31 (May 1978); vol. 31 (August 1978); vol. 32 (January 1979); and vol. 33 (August 1980).

France: Délégation Générale à la Recherche Scientifique et Technique, unpublished statistics.
Japan: Scientific Councelor Embassy of Japan, Washington, D.C., unpublished statistics.
United Kingdom: Cabinet Office, The Central Statistical Office, London, unpublished statistics.
West Germany: Bundesministerium für Forscheng und Technologie, unpublished statistics.
United States: Science Resources Studies, National Science Foundation, unpublished statistics.
U.S.S.R.: Robert W. Campbell, *Reference Source on Soviet R & D Statistics, 1950-1978*, 1978, and Robert W. Campbell, *Soviet R & D Statistics 1977-1980*, National Science Foundation, 1981.

See figure 1-3.

Appendix table 1-4. Estimated ratio of civilian R & D expenditures[1] to gross national product (GNP) for selected countries: 1961-81

Year	France	West Germany	Japan	United Kingdom	United States
	Estimated civilian R & D expenditures as a percent of GNP				
1961	0.97	NA	1.37	1.48	1.20
1962	1.03	1.14	1.46	NA	1.23
1963	1.10	1.26	1.43	NA	1.29
1964	1.34	1.38	1.47	1.49	1.31
1965	1.37	1.53	1.53	NA	1.33
1966	1.40	1.62	1.47	1.58	1.39
1967	1.50	1.70	1.52	1.65	1.48
1968	1.54	1.72	1.59	1.66	1.46
1969	1.52	1.81	1.64	1.66	1.49
1970	1.47	1.96	1.77	NA	1.50
1971	1.33	2.16	1.81	NA	1.46
1972	1.35	2.13	1.81	1.48	1.44
1973	1.30	2.01	1.85	NA	1.43
1974	1.36	2.07	1.91	NA	1.49
1975	1.39	2.19	1.89	1.39	1.50
1976	1.38	2.09	1.88	NA	1.50
1977	1.38	2.14	1.87	NA	1.52
1978	1.35	2.19	NA	1.47	1.54
1979 (prelim.)	NA	2.18	NA	NA	1.57
1980 (est.)	NA	NA	NA	NA	1.63
1981 (est.)	NA	NA	NA	NA	1.66
	Estimated civilian R & D expenditures[2] (national currency in billions)				
1961	3.2	NA	272.8	0.41	6.30
1962	3.8	4.1	316.5	NA	6.93
1963	4.6	4.8	365.2	NA	7.68
1964	6.1	5.8	434.7	.50	8.30
1965	6.7	7.0	504.5	NA	9.22
1966	7.4	7.9	571.6	.61	10.49
1967	8.6	8.4	695.8	.70	11.80
1968	9.7	9.2	868.9	.73	12.79
1969	11.0	10.8	1,055.4	.78	14.10
1970	11.5	13.3	1,333.3	NA	14.86
1971	12.0	16.3	1,508.0	NA	15.73
1972	13.6	17.6	1,758.0	.95	17.06
1973	14.6	18.5	2,173.2	NA	19.01
1974	17.5	20.4	2,655.4	NA	21.33
1975	20.2	22.7	2,892.5	1.45	23.21
1976	23.2	23.5	3,225.5	NA	25.70
1977	26.0	25.6	3,565.1	NA	29.19
1978	28.9	28.2	NA	2.38	33.28
1979 (prelim.)	NA	30.4	NA	NA	37.95
1980 (est.)	NA	NA	NA	NA	42.79
1981 (est.)	NA	NA	NA	NA	48.35

(continued)

Table 1-4. (Continued)

Year	France	West Germany	Japan	United Kingdom	United States
	Gross national product (national currency in billions)				
1961	328.4	333.0	19,852.8	27.5	524.6
1962	367.2	360.5	21,659.5	28.9	565.0
1963	412.0	382.1	25,592.1	30.8	596.7
1964	456.7	419.6	29,661.9	33.5	637.7
1965	489.8	458.2	32,981.6	36.0	691.1
1966	532.0	487.4	38,872.8	38.4	756.0
1967	574.8	493.7	45,896.8	40.5	799.6
1968	630.0	535.2	54,576.8	43.8	873.4
1969	734.0	597.7	64,513.6	47.1	944.0
1970	783.6	679.0	75,523.9	51.6	992.7
1971	873.1	756.0	83,166.0	57.8	1,077.6
1972	961.3	827.2	96,883.1	63.8	1,185.9
1973	1,121.3	920.1	117,257.9	74.1	1,326.4
1974	1,284.4	896.9	139,219.3	84.0	1,434.2
1975	1,455.2	1,034.9	153,126.3	104.7	1,549.2
1976	1,677.8	1,125.0	171,735.6	124.6	1,718.0
1977	1,881.8	1,197.2	190,426.3	142.3	1,918.0
1978	2,135.1	1,287.5	209,248.2	162.5	2,156.1
1979 (prelim.)	NA	1,393.8	NA	NA	2,413.9
1980 (est.)	NA	NA	NA	NA	2,626.1
1981 (est.)	NA	NA	NA	NA	2,920.0

[1] National expenditures for R&D, excluding Government funds for defense and space.
[2] Gross expenditures for performance of R&D including associated capital expenditures, except for the United States, where total capital expenditure data are not available.

NA = Not available

NOTE: The latest data from these sources may be preliminary or estimates.

SOURCES: Calculated from Appendix table 1-3 and data from country sources listed there and Organisation for Economic Co-operation and Development, *Changing Priorities for Government R&D* (Paris: OECD, 1975), and OECD *International Survey of the Resources Devoted to R&D by Member Countries, International Statistical Year — 1973: The Objectives of Government R&D Funding 1970-76* Vol. 2B (Paris: OECD, 1977), and National Science Foundation unpublished statistics.

See figure 1-4.

Science Indicators — 1980

Appendix table 1-5. Estimated distribution of Government R & D expenditures among selected national objectives[1] by country: 1961-79

	National defense	Space	Energy production	Economic development	Health	Community services	Advancement of knowledge[2]
France				National currency in millions			
1961	1,310.0	16.5	735.0	231.6	13.0	12.7	592.3
1967	3,082.0	522.8	1,723.2	1,381.0	116.1	81.0	1,758.1
1972	3,050.0	730.0	1,600.0	2,200.0	200.0	170.0	2,800.0
1975	5,000.0	942.2	1,453.0	4,329.4	680.2	328.7	4,072.2
1976	5,200.0	907.4	1,505.2	4,031.1	755.9	398.4	4,432.6
1978	7,500.0	1,130.0	1,789.0	4,935.0	999.0	556.0	5,519.0
				Percent distribution			
1961	44	1	25	8	(3)	(3)	20
1967	35	6	20	16	1	1	20
1972[4]	28	7	15	20	2	2	26
1975	30	6	9	26	4	2	24
1976	30	5	9	23	4	2	26
1978	33	5	7	21	4	2	24
Japan				National currency in millions			
1961-62	3,162.0	—	5,881.0	25,446.0	724.0	1,071.0	47,321.0
1965-66	4,495.0	141.0	4,944.0	44,898.0	3,679.0	2,818.0	103,163.0
1969-70	6,523.0	2,083.0	22,539.0	69,987.0	5,492.0	7,254.0	185,376.0
1974-75	15,809.0	37,090.0	59,409.0	161,796.0	21,424.0	18,129.0	388,700.0
1977-78	22,021.0	53,244.0	90,109.0	205,505.0	28,514.0	25,422.0	502,811.0
				Percent distribution			
1961-62	4	—	7	30	1	1	56
1965-66	3	(3)	3	27	2	2	63
1969-70	2	1	8	23	2	2	61
1974-75	2	5	8	23	3	3	55
1977-78	2	6	10	22	3	3	54
United Kingdom				National currency in millions			
1961-62	248.6	2.7	56.6	37.9	5.7	0.7	26.0
1966-67	260.4	21.4	65.2	70.9	13.3	2.2	58.4
1972-73	336.8	15.3	69.6	182.8	39.1	8.3	121.8
1974-75	503.1	22.5	68.6	230.6	22.6	13.1	214.9
1975-76	553.5	27.0	87.0	283.3	31.8	17.9	237.1
1977-78	877.2	41.8	128.9	215.7	35.0	40.5	363.8
				Percent distribution			
1961-62	65	1	15	10	2	(3)	7
1966-67	52	4	13	14	3	(3)	12
1972-73	43	2	9	23	5	1	15
1974-75	47	2	6	21	2	1	20
1975-76	46	2	7	20	3	2	20
1977-78	52	2	8	13	2	2	21

(continued)

Table 1-5. (Continued)

	National defense	Space	Energy production	Economic development	Health	Community services	Advancement of knowledge[2]
United States[5]			National currency in millions				
1961-62	7,338.5	1,225.9	755.0	339.1	500.6	99.9	118.2
1966-67	8,264.8	5,307.0	875.0	792.3	968.8	321.1	308.6
1971-72	8,584.7	2,957.6	838.0	1,322.1	1,379.8	729.2	465.4
1974-75	9,620.9	2,511.3	1,163.9	1,784.2	2,247.4	954.6	761.9
1976-77	11,987.1	2,940.3	2,097.9	2,058.5	2,351.9	1,097.1	954.7
1978-79	13,832.9	3,382.9	2,969.2	2,396.9	3,141.0	1,212.9	1,036.4
			Percent distribution				
1961-62	71	12	7	3	5	1	1
1966-67	49	32	5	5	6	2	2
1971-72	53	18	5	8	9	5	3
1974-75	51	13	6	9	12	5	4
1976-77	51	13	9	9	10	5	4
1978-79	49	12	11	9	11	4	4
West Germany			National currency in millions				
1961	381.0	—	267.0	NA	NA	NA	639.0
1966	803.0	177.0	693.0	NA	NA	NA	1,488.0
1971	1,180.0	522.0	1,230.0	1,057.0	195.0	133.0	3,190.0
1975	1,405.0	539.9	1,342.9	1,729.5	414.6	748.7	6,430.7
1976	1,490.5	600.8	1,411.9	1,721.7	448.1	670.8	6,614.5
1978	1,731.8	600.9	1,968.4	2,120.9	534.6	920.5	6,370.8
			Percent distribution				
1961	22	—	16	NA	NA	NA	37
1966	19	4	16	NA	NA	NA	35
1971	15	6	16	13	3	2	41
1975	11	4	11	14	3	6	51
1976	12	5	11	13	3	5	51
1978	12	4	14	15	4	7	45

[1] See Appendix table 1-6 for the components of these objectives.
[2] Excludes general university funds for the United States.
[3] Less than 0.5 percent.
[4] Later estimates indicate that French defense-related R&D expenditures in 1972 were about 32 percent and space R&D, 6 percent of the total government expenditures.
[5] Function categories are not the same as those of appendix table 2-17; e.g., "Advancement of knowledge" does not equal "General science."

NA = Not available

NOTE: Percents may not total 100 because of exclusion of the category "Not specified" and/or because of rounding.

SOURCES: Organisation for Economic Co-operation and Development, *Changing Priorities for Government R&D* (Paris: OECD, 1975); OECD, *International Survey of the Resources Devoted to R&D by Member Countries, International Statistical Year—1973: The Objectives of Government R&D Funding, 1970-76* Vol. 2B (Paris: OECD, 1977); unpublished tabulations from OECD, 1980.

See discussion preceding figure 1.5. Science Indicators—1980

Appendix table 1-6. Classification of Government R & D expenditures shown in Appendix table 1-5.

Category	Components
National defense	R & D directly related to military purposes, including space and nuclear energy activities of a military character.
Space	Civilian space R & D such as manned space flight programs and scientific investigations in space.
Energy production	R & D activities aimed at the supply, production, conservation, and distribution of all forms of energy except as means of propulsion for vehicles and rockets.
Economic development	R&D in a wide range of fields including: agriculture, forestry, and fisheries; mining and manufacturing; transpoortation, telecommunications (including satellite communications), construction, urban and rural planning, and utilities.
0Health	R & D in all of the medical sciences, and in health service management directed toward the protection and improvement of human health.
Community services	R&D for such purposes as environmental protection, educational methods, social and development services, fire and other disaster prevention, planning and statistics, recreation and culture, law and order.
Advancement of knowledge	R&D of a general nature or spanning several fields which cannot be attributed to specific objectives; it consists of R&D expenditures of science councils and private nonprofit institutes. General university funds are included for all countries except the United States.

See Appendix table 1-5.

Science Indicators—1980

Appendix table 1-7. GERD[1] in national currency by source of funds:1967-77

Country and Source	National currency (in millions)				Percent			
	1967	1973	1975	1977	1967	1973	1975	1977
France	12,375.8	19,788.8	26,203.1	33,185.0	100.0	100.0	100.0	100.0
Total domestic	11,965.0	19,116.0	24,847.4	31,321.0	96.7	96.6	94.8	94.4
Industry	3,896.5	7,583.7	10,234.0	13,633.0	31.5	38.3	39.1	41.1
Government and other[2]	8,068.5	11,532.3	14,613.4	17,688.0	65.2	58.3	55.8	53.3
From abroad	410.8	672.8	1,355.7	1,864.0	3.3	3.4	5.2	5.6
Japan	606,293.0	2,147,726.0	2,974,573.0	3,651,314.0	100.0	100.0	100.0	100.0
Total domestic	605,841.0	2,146,344.0	2,972,591.0	3,647,463.0	99.9	99.9	99.9	99.9
Industry	380,794.0	1,318,670.0	1,706,861.0	2,134,247.0	62.8	61.4	57.4	58.5
Government and other[2]	225,047.0	827,674.0	1,265,730.0	1,513,169.0	37.1	38.5	42.6	41.4
From abroad	452.0	1,381.0	1,981.0	3,851.0	.1	.1	.1	.1
United Kingdom[3]	941.8	1,322.6	2,152.2	NA	100.0	100.0	100.0	100.0
Total domestic	905.5	1,251.4	2,047.1	NA	96.2	94.6	95.1	NA
Industry	405.2	571.7	873.0	NA	43.0	43.2	40.6	NA
Government and other[2]	500.3	679.7	1,174.1	NA	53.1	51.4	54.6	NA
From abroad	36.3	71.3	105.1	NA	3.8	5.4	4.9	NA
United States[4]	22,453.0	30,410.6	36,695.0	44,773.8	100.0	100.0	100.0	100.0
Total domestic	22,453.0	30,410.6	36,695.0	44,773.8	100.0	100.0	100.0	100.0
Industry	7,356.0	12,890.4	15,985.8	19,625.5	32.8	42.4	43.0	43.8
Government and other[2]	15,097.0	17,520.2	20,909.2	25,146.8	67.2	57.6	57.0	56.2
From abroad	NA	NA	NA	NA	NA	NA	NA	NA
West Germany	8,337.3	19,232.0	22,969.0	25,733.2	100.0	100.0	100.0	100.0
Total domestic	8,297.4	19,019.0	22,461.0	25,026.0	99.5	98.9	97.8	97.3
Industry	4,794.0	9,357.0	11,514.0	13,595.6	57.5	48.6	50.1	52.8
Government and other[2]	3,503.4	9,661.0	10,947.0	11,430.3	42.0	50.2	47.7	44.4
From abroad	39.9	213.0	508.0	707.3	.5	1.1	2.2	2.7

[1]GERD = Gross Expenditures for Research and Development.
[2]Includes funds from higher education and private non-profit sectors.
[3]All 1973 U.K. figures are from 1972.
[4]All 1967 U.S. figures are from 1966.

NA = not available.

NOTE: Detail may not add to totals because of rounding.

SOURCE: Organisation for Economic Co-operation and Development, *International Survey of the Resources Devoted to R & D by Member Countries, International Statistical Years 1967, 1973, 1975, and 1977* (Paris: OECD)

See figure 1-5.

Science Indicators—1980

Appendix table 1-8. R & D performed in the business enterprise sector by source of funds: 1967-77.

Country and source	National currency (in millions) 1967	1971	1975	1977	Percent 1967	1971	1975	1977
France	6,713.6	8,962.1	15,616.5	19,999.0	100.0	100.0	100.0	100.0
Total domestic	6,422.5	8,439.9	14,393.5	18,425.0	95.7	94.8	92.2	92.1
Business enterprise	3,819.1	5,525.6	9,965.8	13,304.0	56.9	61.7	63.8	66.5
Government	2,602.3	2,939.9	4,376.8	5,058.0	38.8	32.8	28.0	25.3
Private non profit	1.1	21.0	47.2	61.0	(1)	.2	.3	.3
Higher education	—	7.4	3.7	2.0	—	.1	—	(1)
From Abroad	291.1	468.2	1,223.0	1,574.0	4.3	5.2	7.8	7.9
Japan	378,970.0	895,020.0	1,684,847.0	2,109,499.0	100.0	100.0	100.0	100.0
Total domestic	378,890.0	894,192.0	1,683,201.0	2,106,972.0	100.0	99.9	99.9	99.9
Business enterprise	375,112.0	876,607.0	1,651,984.0	2,064,642.0	99.0	97.9	98.0	97.9
Government	3,288.0	17,585.0	28,649.0	39,122.0	.9	2.0	1.7	1.9
Private nonprofit	374.0	—	2,514.0	3,028.0	.1	—	.1	.1
Higher education	116.0	—	54.0	180.0	(1)	—	(1)	(1)
From abroad	80.0	827.0	1,647.0	2,527.0	(1)	.1	.1	.1
United Kingdom[2]	624.4	697.4	1,340.1	NA	100.0	100.0	100.0	NA
Total domestic	601.1	664 8	1,255.4	NA	96.3	95.3	93.7	NA
Business enterprise	387.6	433.8	841.3	NA	62.1	62.2	62.8	NA
Government	200.9	227.7	414.1	NA	32.2	32.6	30.9	NA
Private nonprofit	12.6	3.3	—	NA	2.0	.5	—	NA
Higher education	—	—	—	NA	—	—	—	NA
From abroad	23.3	32.6	84.7	NA	3.7	4.7	6.3	NA
United States[3, 4]	15,541.0	18,314.0	24,164.0	29,907.0	100.0	100.0	100.0	100.0
Total domestic	15,541.0	18,314.0	24,164.0	29,907.0	100.0	100.0	100.0	100.0
Business enterprise	7,254.0	10,643.0	15,559.0	19,362.0	46.7	58.1	64.4	64.7
Government	8,287.0	7,671.0	8,605.0	10,545.0	53.3	41.9	35.6	35.3
Private nonprofit	—	—	—	—	—	—	—	—
Higher education	—	—	—	—	—	—	—	—
From abroad	—	—	—	—	—	—	—	—
West Germany	5,682.9	10,521.0	14,469.0	16,717.1	100.0	100.0	100.0	100.0
Total domestic	5,654.1	10,383.0	14,005.0	16,110.4	99.5	98.7	96.8	96.4
Business enterprise	4,652.3	8,449.0	11,397.0	13,445.6	81.9	80.3	78.8	80.4
Government	986.8	1,915.0	2,596.0	2,648.4	17.4	18.2	17.9	15.8
Private nonprofit	15.0	19.0	12.0	16.4	.3	.2	.1	.1
Higher education	—	—	—	—	—	—	—	—
From abroad	28.8	138.0	464.0	606.7	.5	1.3	3.2	3.6

[1] Less than .05 percent.
[2] U.K. 1971 figures are from 1969/70.
[3] U.S. 1967 figures are from 1966.
[4] Current expenditures plus depreciation only.

NOTE: Details may not add to totals because of rounding.

SOURCE: Organisation of Economic Co-operation and Development, *International Survey of the Resources Devoted to R & D by Member Countries, International Statistical Years,* 1967, 1971, 1975, and 1977, Total Tables, (Paris: OECD).

See text preceding figure 1-6.

Appendix table 1-9. Industrial R&D expenditures as a percentage of the domestic product of industry: 1967-77

[National currency in millions]

Country	BERD[1]	DPI[2]	BERD/DPI (in percent)
United States			
1967	16,385	659,200	2.49
1971	18,314	862,700	2.12
1975	24,164	1,223,200	1.98
1977	29,907	1,563,000	1.91
United Kingdom			
1967	605	30,212	2.00
1971	697	NA	NA
1975	1,340	76,739	1.75
1977	NA	102,663	NA
West Germany			
1967	5,683	444,070	1.28
1971	10,521	682,350	1.54
1975	14,469	912,660	1.59
1977	16,717	1,016,730	1.64
France			
1967	6,292	442,700	1.42
1971	8,962	695,297	1.29
1975	15,617	1,140,204	1.37
1977	19,999	1,476,848	1.35
Japan			
1967	378,969	45,315,500	.84
1971	895,020	80,914,400	1.11
1975	1,684,846	141,173,000	1.19
1977	2,109,499	163,449,000	1.29

[1]Business enterprise R&D (total industrial R&D expenditure.)
[2]The domestic product of industry.

NA = Not available.

NOTE: The industrial R&D expenditures (BERD) and the domestic industrial product (DPI) figures are shown in millions of national currency.

SOURCE: Organisation of Economic Co-operation and Development, *International Survey of the Resources Devoted to R & D by Member Countries, International Statistical Year, 1971,* (Paris: OECD) and unpublished tabulations from OCED, 1980.

See figure 1-6.

Science Indicators—1980

Appendix table 1-10. Productivity[1] growth in manufacturing industries of selected countries: 1960-80

[Index: 1977 = 100]

Year	United States	France	West Germany	Japan	United Kingdom	USSR
1960	60.1	40.0	40.0	21.7	58.3	55.9
1961	61.7	41.9	42.1	24.6	58.8	57.9
1962	64.4	43.8	44.7	25.7	60.3	59.9
1963	69.0	46.4	46.8	27.7	63.5	62.1
1964	72.4	48.7	50.3	31.5	67.9	64.4
1965	74.6	51.5	53.5	32.8	69.9	66.6
1966	75.4	55.2	55.4	36.1	72.5	68.7
1967	75.4	58.2	59.0	41.4	75.6	70.8
1968	78.1	64.8	63.0	46.6	81.2	73.0
1969	79.4	67.2	66.9	53.9	83.1	75.3
1970	79.2	70.6	68.5	60.7	83.2	77.6
1971	84.1	74.3	71.6	63.3	86.1	81.3
1972	88.3	78.6	75.9	69.6	92.2	84.3
1973	93.1	82.9	80.4	77.6	97.5	89.1
1974	90.9	85.8	85.2	80.8	97.2	92.9
1975	93.5	88.4	89.3	84.0	95.0	96.3
1976	97.7	95.7	95.0	91.9	98.8	97.7
1977	100.0	100.0	100.0	100.0	100.0	100.0
1978	100.9	104.9	103.8	106.8	103.2	102.3
1979	101.9	109.8	110.3	115.5	105.8	104.0
1980 (prelim.)	101.4	113.4	109.5	122.7	104.4	NA

[1] Output per hour.

SOURCES: Department of Labor, Bureau of Labor Statistics, Office of Productivity and Technology, "International Comparisons of Manufacturing Productivity and Labor Costs, *Preliminary Measures for 1980,*" May 20, 1981, mimeograph. Productivity figures for Soviet Union were provided by Francis Rushing of SRI International.

See figure 1-7.

Science Indicators—1980

Appendix table 1-11. Real gross domestic product per employed person for selected countries compared with the United States: 1960-80[1]

[Index, United States = 100]

Year	United States	France	West Germany	Japan	United Kingdom	Canada
1950	100	42.7	37.5	15.6	54.0	85.0
1955	100	45.7	45.1	18.9	52.8	88.3
1960	100	54.2	56.6	24.1	54.5	90.4
1965	100	60.2	60.1	31.3	52.5	89.4
1966	100	61.0	62.3	32.9	51.9	87.7
1967	100	63.4	61.5	36.2	53.8	87.9
1968	100	64.0	63.8	39.5	55.0	89.0
1969	100	67.2	67.6	43.8	55.6	90.5
1970	100	71.1	71.3	48.7	57.6	92.6
1971	100	72.7	71.3	49.4	57.5	94.0
1972	100	74.8	72.3	52.6	56.1	94.1
1973	100	76.5	74.2	55.2	56.8	94.2
1974	100	80.3	77.8	56.5	57.4	96.0
1975	100	81.0	78.6	57.2	57.1	94.9
1976	100	82.9	81.7	59.1	57.9	96.3
1977	100	82.7	82.7	60.2	57.2	95.1
1978	100	84.9	84.4	62.7	58.7	94.9
1979	100	87.5	87.1	65.5	59.0	93.9
1980 (prel.)	100	89.4	88.7	68.4	60.5	92.1

[1]Output based on international price weights to enable comparable cross-country comparisons.

SOURCE: Department of Labor, Bureau of Statistics, Office of Productivity and Technology, "Comparative Real Gross Domestic Product, Real GDP per Capita, and Real GDP per Employed Person, 1950-80," May 1981, mimeograph.

See table 1-2 in text.

Science Indicators—1980

Appendix table 1-12. U.S. and world scientific and technical articles[1] by field: 1973-79

Field[2]	1973	1974	1975	1976	1977	1978	1979
	U.S. articles as a percent of all articles						
All fields	38	38	37	37	37	38	37
Clinical medicine	43	43	43	43	43	43	43
Biomedicine	39	38	39	39	39	39	40
Biology	46	46	45	44	42	42	43
Chemistry	23	22	22	22	22	21	21
Physics	33	33	32	31	30	31	30
Earth and space sciences	47	47	44	46	45	45	45
Engineering and technology	42	42	41	41	40	39	41
Mathematics	48	46	44	43	41	40	40
	Number of U.S. articles[3]						
All fields	103,777	100,066	97,278	99,970	97,854	99,207	99,377
Clinical medicine	32,638	31,691	31,334	32,920	33,516	34,966	33,975
Biomedicine	16,115	15,607	15,901	16,271	16,197	16,611	17,649
Biology	11,150	10,700	10,400	10,573	9,904	9,663	10,553
Chemistry	10,474	9,867	9,222	9,337	8,852	9,266	9,182
Physics	11,721	11,945	11,363	11,502	10,995	11,015	10,995
Earth and space sciences	5,591	5,371	4,975	5,537	5,197	5,043	5,167
Engineering and technology	11,955	11,088	10,431	10,346	10,081	9,694	9,018
Mathematics	4,134	3,797	3,652	3,484	3,112	2,949	2,838
	Number of all articles						
All fields	271,513	265,130	260,908	267,354	263,700	270,128	267,953
Clinical medicine	76,209	74,509	73,485	76,599	77,597	81,209	78,827
Biomedicine	41,155	40,632	41,244	41,891	41,388	42,968	43,631
Biology	24,047	23,414	23,260	23,905	23,757	23,176	24,734
Chemistry	45,004	44,529	42,502	42,773	40,734	43,550	43,273
Physics	35,864	35,708	35,104	36,902	36,057	35,515	36,700
Earth and space sciences	11,977	11,479	11,356	12,011	11,531	11,224	11,596
Engineering and technology	28,617	26,600	25,664	25,146	25,063	24,588	22,182
Mathematics	8,639	8,259	8,293	8,127	7,573	7,298	7,011

[1] Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.
[2] See appendix table 1-13 for the subfields included in these fields.
[3] When an article is written by researchers from more than one country, that article is prorated across the countries involved. For example, if a given article has several authors from France and the United States, it is split on the basis of these countries regardless of the number of organizations represented by the authors.

NOTE: Detail may not add to totals because of rounding.

SOURCE: Computer Horizons, Inc., unpublished data.

See table 1-4 in text.

Science Indicators—1980

Appendix table 1-13. Fields and subfields of international scientific literature

Clinical medicine
- General & internal medicine
- Allergy
- Anesthesiology
- Cancer
- Cardiovascular system
- Dentistry
- Dermatology & venereal diseases
- Endocrinology
- Fertility
- Gastroenterology
- Geriatrics
- Hematology
- Immunology
- Obstetrics & gynecology
- Neurology & neurosurgery
- Ophthalmology
- Orthopedics
- Arthritis & rheumatism
- Otorhinolaryngology
- Pathology
- Pediatrics
- Pharmacology
- Pharmacy
- Psychiatry
- Radiology & nuclear medicine
- Respiratory system
- Surgery
- Tropical medicine
- Urology
- Nephrology
- Veterinary medicine
- Addictive diseases
- Hygiene & public health
- Miscellaneous clinical medicine

Biomedical research
- Physiology
- Anatomy & morphology
- Embryology
- Genetics & heredity
- Nutrition & dietetics
- Biochemistry & molecular biology
- Biophysics
- Cell biology cytology & histology
- Microbiology
- Virology
- Parasitology
- Biomedical engineering
- Microscopy
- Miscellaneous biomedical research
- General biomedical research

Biology
- General biology
- General zoology
- Entomology
- Miscellaneous zoology
- Marine biology & hydrobiology
- Botany
- Ecology
- Agriculture & food science
- Miscellaneous biology

Chemistry
- Analytical chemistry
- Organic chemistry
- Inorganic & nuclear chemistry
- Applied chemistry
- General chemistry
- Polymers
- Physical chemistry

Physics
- Chemical physics
- Solid state physics
- Fluids & plasmas
- Applied physics
- Acoustics
- Optics
- General physics
- Nuclear & particle physics
- Miscellaneous physics

Earth and space science
- Astronomy & astrophysics
- Meteorology & atmospheric science
- Geology
- Earth & planetary science
- Geography
- Oceanography & limnology

Engineering and technology
- Chemical engineering
- Mechanical engineering
- Civil engineering
- Electrical engineering & electronics
- Miscellaneous engineering & technology
- Industrial engineering
- General engineering
- Metals & metallurgy
- Materials science
- Nuclear technology
- Aerospace technology
- Computers
- Library & information science
- Operations research & management science

Psychology
- Clinical psychology
- Personality & social psychology
- Developmental & child psychology
- Experimental psychology
- General psychology
- Miscellaneous psychology
- Behavioral science

Mathematics
- Algebra
- Analysis & functional analysis
- Geometry
- Logic
- Number theory
- Probability
- Statistics
- Topology
- Computing theory & practice
- Applied mathematics
- Combinatorics & finite mathematics
- Physical mathematics
- General mathematics
- Miscellaneous mathematics

Appendix table 1-14. Relative citation ratios[1] for U.S. articles[2] by field: 1973-77

Source of citations	Year	All fields[3]	Clinical medicine	Biomedicine	Biology	Chemistry	Physics	Earth and space sciences	Engineering and technology	Mathematics
World citations to U.S.	1973	1.87	1.73	1.88	1.33	2.38	2.19	1.80	1.76	1.55
	1974	1.87	1.74	1.91	1.36	2.37	2.16	1.80	1.71	1.54
	1975	1.88	1.75	1.85	1.37	2.42	2.21	1.90	1.72	1.58
	1976	1.85	1.74	1.82	1.36	2.40	2.27	1.73	1.66	1.55
	1977	1.84	1.73	1.76	1.39	2.47	2.29	1.82	1.75	1.65
U.S. citations to U.S.	1973	2.55	2.24	2.43	1.98	3.97	3.06	2.15	2.51	2.08
	1974	2.61	2.30	2.50	2.08	4.17	3.08	2.16	2.53	2.15
	1975	2.63	2.28	2.47	2.13	4.21	3.19	2.32	2.60	2.21
	1976	2.63	2.29	2.47	2.16	4.21	3.30	2.13	2.53	2.25
	1977	2.65	2.30	2.47	2.28	4.16	3.38	2.22	2.53	2.37
Non-U.S. citations to U.S.	1973	1.30	1.23	1.38	.79	1.60	1.62	1.33	1.13	.99
	1974	1.25	1.20	1.33	.76	1.50	1.52	1.30	.97	.95
	1975	1.25	1.20	1.28	.76	1.53	1.55	1.39	.99	.98
	1976	1.21	1.18	1.24	.72	1.47	1.59	1.22	.91	.93
	1977	1.16	1.13	1.13	.72	1.48	1.54	1.31	.97	.96

[1]A citation ratio of 1.00 reflects no over- or under-citing of the U.S. scientific and technical literature, whereas a higher ratio indicates a greater influence, impact or utility than would have been expected from the number of U.S. articles for that year. For example, the U.S. biology literature for 1973 received 33 percent more citations from the world literature of later years than could be accounted for by the U.S. share of the world's biology articles published in 1973.

[2]Based on the articles, notes and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* corporate tapes of the Institute for Scientific Information. For the size of this data base, see appendix table 1-12.

[3]See Appendix table 1-13 for a description of the subfields included in these fields. Note that because psychology journals began to be removed from the *SCI* in 1978 for inclusion in the *Social Sciences Citation Index,* the "All fields" totals for all years exclude psychology articles.

NOTE: These ratios are calculated by a new method that used citations from subsequent years to describe the influence of a given year's literature; thus they differ from similar indexes used in previous *Science Indicators* reports.

See table 1-5 in text.

Appendix table 1-15. U.S. patents granted to inventors from selected countries, by date of grant and nationality of inventor: 1966-79

Country	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Total	68,405	65,652	59,103	67,559	64,429	78,316	74,806	74,142	76,278	71,998	70,219	65,269	66,079	48,852
United States	54,634	51,274	45,783	50,397	47,075	55,976	51,516	51,503	50,645	46,708	44,271	41,484	41,233	30,069
Foreign	13,771	14,378	13,320	17,162	17,354	22,340	23,290	22,639	25,633	25,290	25,948	23,785	24,846	18,783
West Germany	3,981	3,766	3,442	4,523	4,434	5,519	5,728	5,588	6,157	6,035	6,179	5,537	5,849	4,528
Japan	1,122	1,424	1,464	2,152	2,625	4,032	5,152	4,939	5,889	6,352	6,543	6,217	6,911	5,252
United Kingdom	2,674	2,800	2,481	3,178	2,954	3,468	3,170	2,854	3,145	3,043	2,991	2,651	2,722	1,910
France	1,435	1,558	1,446	1,808	1,732	2,214	2,231	2,143	2,565	2,367	2,407	2,108	2,119	1,605
Switzerland	983	948	822	1,058	1,112	1,281	1,305	1,326	1,453	1,457	1,475	1,347	1,329	1,025
Canada	938	991	897	994	1,065	1,326	1,243	1,345	1,325	1,296	1,192	1,219	1,226	865
U.S.S.R.	66	115	95	159	218	334	355	382	492	421	426	394	412	354
Other E.E.C. countries[1]	782	821	744	937	928	1,203	1,194	1,157	1,294	1,073	1,291	1,151	1,128	847

[1] Other European Economic Community (E.E.C.) countries included here are Belgium, Denmark, Ireland, Luxembourg, and the Netherlands. Data for Italy are not comparable for use in this indicator.

NOTE: U. S. patent counts for 1979 are unreliable because the Patent and Trademark Office did not have enough money in that year to print all approved patents.

SOURCE: Office of Technology Assessment and Forecast, U. S. Patent and Trademark Office, *Indicators of Patent Output of U. S. Industry IV (1963-1979)*, 1980.

See figure 1-8.

Appendix table 1-16. Patents granted in selected countries by nationality of inventor: 1966-77

Country	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
United States												
Total	68,406	65,652	59,102	67,557	64,427	78,136	74,818	74,139	76,275	71,994	70,236	65,269
Granted to nationals	54,634	51,274	45,782	50,395	47,073	55,988	51,515	51,501	50,643	46,603	44,162	41,383
Granted to all foreigners	13,772	14,378	13,320	17,162	17,354	22,328	23,293	22,638	25,632	23,391	26,074	23,886
Foreign patents granted to U.S.[1]	49,098	47,982	48,229	50,852	48,807	49,849	49,628	43,326	39,990	39,300	38,028	39,477
West Germany												
Total	22,598	19,871	21,169	22,623	12,887	18,149	20,600	23,934	20,539	18,290	20,965	21,749
Granted to nationals	13,095	11,520	12,143	12,432	6,386	8,295	9,642	11,191	9,793	9,077	10,395	10,815
Granted to U.S.	3,733	3,406	3,804	4,483	2,882	4,393	4,575	4,949	3,913	3,140	3,333	3,488
Granted to all foreigners	9,503	8,351	9,026	10,191	6,501	9,854	10,958	12,743	10,746	9,213	10,570	10,934
U.S. patents as percent of foreigners	39.3	40.8	42.1	44.0	44.3	44.6	41.8	38.8	36.4	34.1	31.5	31.9
Japan												
Total	26,315	20,773	27,972	27,657	30,818	36,447	41,454	42,328	39,626	46,728	40,317	52,608
Granted to nationals	17,373	13,877	18,576	18,787	21,403	24,795	29,101	30,937	30,873	36,992	32,465	43,047
Granted to U.S.	4,683	3,432	4,903	4,657	4,774	5,700	5,948	5,485	4,432	4,918	4,029	4,884
Granted to all foreigners	8,942	6,896	9,396	8,870	9,475	11,652	12,353	11,391	8,753	9,736	7,852	9,561
U.S. patents as percent of foreigners	52.4	49.8	52.2	52.5	50.4	48.9	48.2	48.2	50.6	50.5	51.3	51.1
United Kingdom												
Total	37,272	38,999	43,038	38,790	40,995	41,554	42,794	39,844	37,808	40,689	39,797	36,549
Granted to nationals	NA	NA	NA	9,807	10,343	10,376	10,116	9,357	8,971	9,120	8,855	7,722
Granted to U.S.	14,117	13,676	12,588	12,678	12,728	12,682	13,001	11,717	10,976	11,497	11,024	10,420
Granted to all foreigners	NA	NA	NA	28,893	30,652	31,178	32,678	30,487	28,837	31,569	30,942	28,827
U.S. patents as percent of foreigners	NA	NA	NA	43.9	41.5	40.7	39.8	38.4	38.1	36.4	35.6	36.1
France												
Total	43,950	46,995	47,990	32,020	26,297	51,456	46,217	27,939	24,725	14,320	29,754	31,045
Granted to nationals	14,881	15,246	15,627	10,288	17,758	13,696	10,767	10,817	9,282	4,962	8,420	8,361
Granted to U.S.	9,807	10,911	10,794	6,943	5,664	11,973	11,206	5,047	4,719	2,801	6,171	6,671
Granted to all foreigners	29,069	31,749	32,363	21,732	8,539	37,760	35,450	17,122	15,443	9,358	21,334	22,684
U.S. patents as percent of foreigners	33.7	34.4	33.4	31.9	66.3	31.7	31.6	29.5	30.6	29.9	28.93	29.4
Switzerland												
Total	22,507	21,850	17,450	16,775	17,575	16,079	14,921	13,680	12,970	13,700	12,300	22,555
Granted to nationals	6,174	5,388	4,277	4,260	4,452	4,165	3,942	3,959	3,647	3,794	3,482	6,320
Granted to U.S.	3,468	3,632	3,126	3,110	3,090	2,736	2,528	2,140	2,101	2,070	1,847	3,191
Granted to all foreigners	16,333	16,462	13,173	12,515	13,123	11,914	10,979	9,721	9,323	9,906	8,818	16,235
U.S. patents as percent of foreigners	21.2	22.1	23.7	24.9	23.5	23.0	23.0	22.0	22.5	20.9	20.9	19.7
Canada												
Total	24,417	25,836	25,806	28,981	29,193	29,242	29,295	21,246	21,287	20,544	21,750	20,793
Granted to nationals	1,222	1,263	1,263	1,461	1,395	1,587	1,551	1,218	1,368	1,208	1,301	1,291
Granted to U.S.	16,614	17,583	17,583	19,147	18,663	17,992	17,289	12,964	12,785	12,220	12,411	11,931
Granted to all foreigners	23,195	24,573	24,543	27,520	27,798	27,655	26,744	20,028	19,919	19,264	20,449	19,502
U.S. patents as percent of foreigners	71.6	71.6	71.6	69.6	67.1	65.1	64.6	64.7	64.2	63.4	60.7	61.2
Other EEC countries[2]												
Total	25,505	24,133	24,627	26,263	26,124	24,322	24,752	25,280	23,341	22,276	21,713	22,609
Granted to nationals	2,423	2,337	2,089	2,233	2,078	2,023	2,156	2,074	1,869	1,759	1,720	1,801
Granted to U.S.	6,483	6,253	6,225	6,777	6,670	6,346	6,287	6,071	5,783	5,455	5,384	5,563
Granted to all foreigners[3]	23,082	21,796	22,538	24,030	24,046	22,299	22,596	23,206	21,472	20,517	19,993	20,808
U.S. patents as percent of foreigners	28.1	28.7	27.6	28.2	27.7	28.5	27.8	26.2	26.9	26.6	24.8	26.7

[1] Includes patents granted to U.S. inventors by all the countries shown here (West Germany, Japan, the United Kingdom, Switzerland, Canada, and "other EEC countries"). Patents granted by France are not included due to the wide fluctuations in French patents granted to foreigners.

[2] Other European Economic Community (E.E.C.) countries included here are Belgium, Denmark, Ireland, Luxembourg, and the Netherlands. Comparable data for Italy are not available.

[3] Based on each country as a unit rather than the group of nations as a unit. For instance, patents granted to Denmark by the Netherlands are considered as non-resident or foreign patents here.

NA = not available.

SOURCE: World Intellectual Property Organization, *Industrial Property Statistics* (Geneva: WIPO, annual issues of 1967-79).

See figure 1-9.

Appendix table 1-17. Number of U.S. Patents granted to selected foreign countries by product field for the period 1963-79

	All fields	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
Total	1,106,763	12,426	11,268	179,715	25,890	15,233	57,772	26,409	14,722	142,355	347,567	121,704	129,450	70,323	23,998	131,533
U.S.	788,287	8,729	7,484	116,257	14,860	13,107	42,683	19,452	9,350	108,696	242,601	89,500	93,846	49,173	15,311	93,177
Foreign	318,476	3,697	3,784	63,458	11,030	2,126	15,089	6,957	5,372	33,659	104,966	32,204	35,604	21,150	8,687	38,356
W. Germany	79,343	489*	1,140*	18,269*	2,555*	374*	3,482*	1,474*	1,098*	7,845*	27,462*	7,497*	6,889*	5,856*	2,326*	9,421*
Japan	61,943	1,284*	677*	12,535*	1,744*	268*	3,032*	1,398*	1,173*	4,896*	16,687*	6,733*	10,491*	3,593*	1,975*	10,246*
U. Kingdom	46,253	405*	638*	8,114*	1,430*	485*	2,481*	1,260*	714*	5,546*	15,699*	4,999*	5,461*	3,763*	1,703*	4,842*
France	30,970	254	282*	5,876*	1,344*	202	1,511*	743*	530*	3,520*	9,761*	3,363*	3,920*	2,637*	1,109*	3,149*
Switzerland	19,110	199	403*	6,265*	1,300*	47	649	234	228	1,703*	5,723	1,722	1,110	769	158	2,181
Canada	18,025	217	114	2,063	380	305	967	397	384	2,704	6,352	1,667	1,594	1,235	325	1,500
Sweden	11,771	107	87	818	264	37	650	343	282	1,923	5,051	1,228	925	957	261	1,305
Italy	10,268	97	122	2,687	522	42	494	168	133	943	3,675	935	696	557	200	776
Netherlands	9,813	201	69	1,884	303	159	414	196	83	928	2,820	1,327	2,425	323	117	876
U.S.S.R.	4,278	40	20	620	78	53	73	95	159	294	1,892	678	384	131	62	507
Belgium	3,951	32	45	935	140	29	204	147	78	362	1,057	243	335	143	26	843
Austria	3,538	29	21	364	78	16	179	75	147	450	1,540	233	253	167	58	398
Australia	3,001	41	37	390	68	15	178	78	69	475	1,162	211	174	178	62	405
Denmark	2,234	68	26	288	101	7	141	70	10	353	857	259	147	55	27	327
Mexico	992	24	5	421	337	3	37	13	24	101	232	39	18	45	21	69
Other foreign	12,986	210	98	1,929	386	84	597	266	260	1,616	4,996	1,070	782	741	257	1,511

[1]Countries were selected on the basis of being in the top 10 of at least one of the Standard Industrial Classifications.
*Indicates ranking among the top five foreign countries in this particular product field
[2]Other foreign includes patents granted to foreign countries not shown separately.

I Food and kindred products
II Textile mill products
III Chemicals, except drugs and medicines
IV Drugs and medicines
V Petroleum and gas extraction and petroleum refining
VI Rubber and miscellaneous plastics products
VII Stone, clay, glass, and concrete products
VIII Primary metals
IX Fabricated metals
X Nonelectrical machinery
XI Electrical equipment except communication equipment
XII Communication equipment and electronic components
XIII Motor vehicles and other transportation equipment except aircraft
XIV Aircraft and parts
XV Professional and scientific instruments

SOURCE: Compiled from information in Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, *Indicators of the Patent Output of U.S. Industry* IV (1963-79), 1980

See discussion in the section on "Foreign Patenting in the United States."

Appendix table 1-18. U.S. International transactions in royalties and fees: 1967-78

[Dollars in millions]

Year	Balance	Receipts	Payments
1967	$1,350	$1,516	$166
1968	1,497	1,683	186
1969	1,621	1,842	221
1970	1,909	2,134	225
1971	2,134	2,375	241
1972	2,272	2,566	294
1973	2,636	3,021	385
1974	3,238	3,584	346
1975	3,535	4,008	473
1976	3,602	4,084	482
1977	4,040	4,474	434
1978 (prel.)	4,819	5,429	610

SOURCE: Based on Appendix table 1-19.

See figure 1-10. Science Indicators — 1980

Appendix table 1-19. U.S. receipts and payments of royalties and fees[1] with selected nations: 1967-78

[Dollars in millions]

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978 (prel.)
Total net receipts[2]	$1,516	$1,683	$1,842	$2,134	$2,375	$2,566	$3,021	$3,584	$4,008	$4,084	$4,474	$5,429
Developed countries	1,152	1,271	1,404	1,651	1,856	2,031	2,421	2,857	3,177	3,273	3,639	4,381
United Kingdom	208	214	238	273	306	334	376	427	523	520	558	742
European Community[3]	334	388	431	511	585	631	794	954	1,091	1,043	1,187	1,466
Other Europe	107	112	135	142	163	188	216	276	337	345	410	418
Canada	275	296	295	344	365	394	426	555	585	651	694	759
Japan	132	175	208	268	306	342	426	439	419	485	554	744
AZSA[4]	86	86	97	113	131	142	183	206	222	222	236	252
Developing countries	365	411	440	483	520	536	599	726	831	813	837	1,046
Total net payments[5]	166	186	221	225	241	294	385	346	473	482	434	610
Developed countries[6]	163	183	217	216	234	289	376	346	452	451	481	574
United Kingdom	43	56	67	54	48	59	73	84	103	85	91	159
European Community[3]	43	51	54	54	58	63	95	75	84	92	100	178
Other Europe	27	22	27	34	54	93	114	173	135	149	120	148
Canada	46	51	60	66	69	66	79	53	148	146	126	137
Japan	11	7	8	8	5	7	14	−35	−17	−21	−18	−51
AZSA[4]	14	14	8	14	14	8	8	−4	−1	(7)	−1	3
Developing countries[6]	4	4	5	9	7	6	10	−1	20	33	16	38

[1]Excludes film rentals which are included with receipts and payments of royalties and fees in the international transactions tables in the *Survey of Current Business.*

[2]Represents net receipts of payments by U.S. firms from their foreign affiliates for the use of intangible property such as patents. techniques, processes, formulas, designs, trademarks, copyrights, franchises, manufacturing rights, management fees, etc.

[3]Original six members only.

[4]AZSA = Australia, New Zealand, and the Republic of South Africa.

[5]Payments measure net transactions between U.S.affiliates and their foreign parents.

[6]Estimates within plus or minus $0.5 million of the actual totals.

[7]Less than $0.5 million.

NOTE:Detail may not add to totals because of rounding. Negative payments represent foreign liabilities to U.S.-based affiliates.

SOURCE: Appendix tables 1-20 and 1-21.

Science Indicators—1980

Appendix table 1-20. U.S. receipts and payments of royalties and fees[1] associated with foreign direct-investment: 1967-78

[Dollars in Millions]

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978 (prel.)
Total net receipts[2]	$1,123	$1,246	$1,356	$1,561	$1,757	$1,911	$2,309	$2,833	$3,251	$3,262	$3,554	$4,364
Developed countries	809	893	975	1,142	1,299	1,448	1,783	2,200	2,522	2,570	2,849	3,466
United Kingdom	153	161	183	217	240	271	302	356	444	448	476	649
European Community[3]	237	275	297	354	424	473	625	767	892	833	961	1,205
Other Europe	78	79	99	104	112	131	157	203	257	258	286	307
Canada	242	265	267	311	333	356	394	517	547	613	652	698
Japan	37	45	53	66	83	102	153	190	200	239	279	401
AZSA[4]	62	68	76	90	107	115	152	167	182	179	195	206
Developing countries	315	352	382	418	458	464	525	632	729	693	707	896
Total net payments[5]	62	80	101	111	118	155	209	160	287	293	243	396
Developed countries[6]	62	80	101	108	115	154	208	167	270	267	237	374
United Kingdom	11	21	26	19	11	15	20	17	27	8	19	75
European community[3]	−3	(7)	2	2	3	6	23	5	17	25	37	111
Other Europe	11	9	13	21	36	72	91	151	115	132	99	125
Canada	43	47	56	62	64	60	73	46	139	137	118	127
Japan	(7)	3	4	4	1	1	1	−47	−26	−34	−34	−66
AZSA[4]	(7)	(7)	(7)	(7)	(7)	(7)	(7)	−5	−2	−1	−2	2
Developing countries[6]	1	1	1	2	3	1	1	−9	16	27	4	23

[1]Excludes film rental which are included with receipts and payments of royalties and fees in the international transactions tables in the *Survey of Current Business.*

[2]Represent net receipts of payments by U.S. firms from their foreign affiliates for the use of intangible property such as patents, techniques, processes, formulas, designs, trademarks, copyrights, franchises, manufacturing rights, management fees, etc.

[3]Original six members only.

[4]AZSA = Australia, New Zealand, and the Republic of South Africa.

[5]Payments measure net transactions between U.S. affiliates and their foreign patents for the use of intangible property.

[6]Estimates within plus or minus $0.5 million of the actual totals.

[7]Less than $0.5 million.

NOTE: Detail may not add to totals because of rounding. Negative payments represent foreign liabilities to U.S.-based subsidiaries.

SOURCE: Meryl L. Kroner, "U.S. International Transactions in Royalties and Fees, 1967-78;" *Survey of Current Business,* vol. 60 (January 1980), p. 34.

See appendix tables 1-18 and 1-19.

Appendix table 1-21. U.S. receipts and payments of royalties and fees associated with unaffiliated foreign residents[1], 1967-78

[Dollars in Millions]

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978 (prel.)
Total net receipts[2]	$393	$437	$486	$573	$618	$655	$712	$751	$757	$822	$920	$1,065
Developed countries	343	378	429	509	557	583	638	657	655	703	790	915
United Kingdom	55	53	55	56	66	63	74	71	79	72	82	93
European Community[3]	107	113	134	157	161	156	169	187	199	210	226	261
Other Europe	29	33	36	38	51	57	59	73	80	87	124	111
Canada	33	31	28	33	32	38	32	38	38	45	42	61
Japan	95	130	155	202	223	240	273	249	219	246	275	343
AZSA[4]	24	18	21	23	24	27	31	39	40	43	41	46
Developing countries	50	59	58	65	62	72	74	94	102	120	130	150
Total Net payments[5]	104	106	120	114	123	139	176	186	186	189	191	214
Developed countries[6]	101	103	116	108	119	135	168	179	182	184	181	200
United Kingdom	32	35	41	35	37	44	53	67	76	77	72	84
European community[3]	46	47	52	52	55	57	72	70	67	67	63	67
Other Europe	16	13	14	13	18	21	23	22	20	17	21	23
Canada	3	4	4	4	5	6	6	7	9	9	8	10
Japan	4	4	4	4	4	6	13	12	9	13	16	15
AZSA[4]	(7)	(7)	1	(7)	(7)	1	1	1	1	1	1	1
Developing countries[6]	3	3	4	7	4	5	9	8	4	6	12	15

[1]Excludes film rental which are included with receipts and payments of royalties and fees in the international transactions tables in the *Survey of Current Business.*

[2]Represent net receipts of payments by U.S. firms from foreign residents or organizations other than their subsidiaries for the use of intangible property such as patents, techniques, processes, formulas, designs, trademarks, copyrights, franchises, manufacturing rights, management fees, etc.

[3]Original six members only.

[4]AZSA = Australia, New Zealand, and the Republic of South Africa.

[5]Payments measure net payments by U.S. residents to independent foreign residents for the use of intangible property.

[6]Estimates within plus or minus $0.5 million of the actual totals.

[7]Less than $0.5 million.

NOTE: Detail may not add to totals because of rounding.

SOURCE: Meryl L. Kroner, "U.S. International Transactions in Royalties and Fees, 1967-78;" *Survey of Current Business*, vol. 60 (January 1980), p. 25.

See appendix tables 1-18 and 1-19.

Appendix table 1-22. U.S. direct investment abroad in manufacturing for selected nations and industry groups: 1966-78

[Millions of U.S. dollars]

Country	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978 (prel.)
All countries (1)	$20,740	$22,803	$25,160	$28,332	$31,049	$34,359	$38,325	$44,370	$51,172	$55,886	$61,161	$66,033	$74,207
Chemical products	3,840	4,541	5,068	5,539	5,865	6,519	7,253	8,415	10,172	11,107	12,183	13,466	16,097
Machinery	5,033	5,455	5,986	7,012	7,842	8,930	10,096	11,811	13,992	15,595	17,091	18,655	21,137
Developed countries (1)	17,214	18,912	20,721	23,285	25,572	28,320	31,558	36,550	41,973	45,427	49,766	53,709	60,135
Chemical products	2,857	3,396	3,803	4,164	4,419	4,959	5,500	6,488	7,821	8,471	9,295	10,192	12,176
Machinery	4,473	4,866	5,317	6,223	6,931	7,907	8,917	10,259	12,003	13,231	14,338	15,715	17,785
Canada (1)	6,697	7,059	7,535	8,404	8,971	9,504	10,491	11,755	13,450	14,691	15,965	16,696	17,625
Chemical products	1,058	1,146	1,222	1,297	1,320	1,453	1,583	1,767	2,049	2,268	2,462	2,373	2,896
Machinery	1,345	1,424	1,508	1,743	1,773	1,891	2,111	2,325	2,682	3,042	3,246	3,470	3,580
All Western Europe (1)	8,906	9,867	10,940	12,372	13,819	15,628	17,529	20,777	23,990	26,013	28,788	31,672	36,426
Chemical products	1,523	1,793	2,058	2,271	2,451	2,792	3,146	3,818	4.757	5,161	5,756	6,672	7,953
Machinery	2,681	2,930	3,226	3,829	4,383	5,097	5,727	6,743	7,971	8,774	9,550	10,489	12,104
France (1)	1,162	1,260	1,303	1,464	1,812	2,107	2,441	2,943	3,428	3,844	3,997	4,139	4,629
Chemical products	164	215	226	266	299	330	390	453	543	592	638	699	772
Machinery	443	443	456	503	620	744	834	1,011	1,194	1,415	1,405	1,511	1,782
United Kingdom (1)	3,568	3,751	4,159	4,492	4,909	5,427	5,779	6,611	7,371	7,555	7,734	8,849	10,070
Chemical products	591	608	632	644	702	819	870	1,042	1,221	1,262	1,327	1,578	2,060
Machinery	1,049	1,146	1,197	1,412	1,590	1,744	1,853	2,008	2,293	2,405	2,500	2,832	3,121
Germany (1)	1,748	1,956	2,149	2,581	2,675	3,107	3,637	4,442	4,814	5,328	6,706	7,031	8,324
Chemical products	179	200	239	259	295	373	425	578	691	770	915	1,005	1,370
Machinery	526	583	692	906	976	1,172	1,388	1,683	1,949	2,101	2,436	2,664	3,098
Japan (1)	366	442	527	645	768	978	1,185	1,399	1,520	1,557	1,691	1,903	2,317
Chemical products	87	103	131	161	180	209	244	301	327	360	374	406	490
Machinery	222	266	(2)	(2)	(2)	511	633	732	775	787	862	999	1,269
Developing countries (1)	3,525	3,891	4,439	5,047	5,477	6,038	6,767	7,820	9,200	10,459	11,395	12,324	14,071
Chemical products	983	1,145	1,264	1,375	1,446	1,561	1,753	1,927	2,351	2,636	2,888	3,274	3,921
Machinery	560	589	669	789	910	1,023	1,178	1,552	1,989	2,364	2,752	2,939	3,352

(1) = Total manufacturing.
(2) = These data are withheld by the Commerce Department to avoid disclosure of data for individual companies.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Selected Data on U.S. Direct Investment Abroad, 1966-78*, 1980.

See discussion preceding text table 1-8.

Appendix table 1-23. Transfers of innovations by U.S.-based multinational enterprises to their manufacturing subsidiaries abroad by R&D intensity of the parent: 1945-77

Innovations classified by R&D expenditures of parent	Number of innovations[1]	Percentage transferred abroad, by number of years between U.S. introduction and initial transfer						Average annual transfer rate from year of first foreign introduction to:	
		Less than 2 years after	2 or 3 years after	4 or 5 years after	6 to 9 years after	10 or more years after	Total	3rd year there-after	1977 year end
Parent's R&D expenditures as percent of sales:									
Under 2 percent	108	22.2	12.1	15.7	13.0	14.7	77.7	0.803	0.349
2 to under 4 percent	190	14.7	16.3	10.0	16.3	21.6	78.9	1.003	.293
4 percent and over	108	22.2	20.4	11.1	13.0	22.2	88.9	1.067	.331
Parent's R&D expenditures as percent of sales, normalized by parent industry:									
Under 100 percent	152	13.8	12.5	11.8	23.0	17.8	78.9	.777	.302
100 to under 200 percent	123	17.1	17.1	15.5	16.3	13.0	79.0	1.000	.302
200 percent and over	131	26.0	19.8	8.4	21.3	10.0	85.5	1.297	.382
Total	406	18.7	16.3	11.6	14.3	20.2	81.1	1.017	.326

[1]Transfers of 406 innovations by 57 U.S.-based multinational enterprises.

SOURCE: Raymond Vernon and W.H. Davidson, *Foreign Production of Technology-Intensive Products by U.S.-Based Multinational Enterprises*, National Science Foundation, 1979, p. 55.

See text table 1-8.

Appendix table 1-24. U.S. trade balance[1] in R & D-intensive and non-intensive manufactured product groups: 1960-79.

[Dollars in millions]

Year	R & D-intensive			Non-R & D-intensive		
	Balance	Export	Import	Balance	Export	Import
1960	$ 5,891	$ 7,597	$ 1,706	-$179	$ 4,962	$ 5,141
1961	6,237	8,018	1,781	-12	4,730	4,742
1962	6,720	8,715	1,995	-691	4,940	5,631
1963	6,958	8,975	2,017	-765	5,284	6,049
1964	7,970	10,267	2,297	-678	6,121	6,799
1965	8,148	11,078	2,930	-2,027	6,281	8,308
1966	7,996	12,174	4,178	-3,325	6,913	10,238
1967	8,817	13,407	4,590	-3,729	7,437	11,166
1968	9,775	15,312	5,537	-6,581	8,506	15,087
1969	10,471	16,955	6,484	-6,698	9,830	16,528
1970	11,722	19,274	7,552	-8,285	10,069	18,354
1971	11,727	20,228	8,501	-11,698	10,215	21,913
1972	11,012	22,003	10,991	-15,039	11,737	26,776
1973	15,101	29,088	13,987	-15,370	15,643	31,013
1974	23,873	41,111	17,238	-15,573	22,412	37,985
1975	29,344	46,439	17,095	-9,474	24,511	33,985
1976	28,964	50,830	21,866	-16,499	26,411	42,910
1977	27,107	53,370	26,263	-23,509	26,781	50,290
1978	29,598	63,908	34,310	-35,379	30,627	66,006
1979	39,270	79,117	39,847	-34,828	37,559	72,387

[1]Exports less imports.

SOURCE: Department of Commerce, Domestic and International Business Administration, *Overseas Business Reports* August 1967, April 1972, April 1977, August 1979, and July 1980.

See figure 1-12.

Science Indicators—1980

Appendix table 1-25. U.S. trade balance[1] in selected R&D-intensive manufactured product groups: 1960-79

[Dollars in millions]

Product groups	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Chemicals[2]																				
Balance	$ 955	$1,051	$1,104	$1,294	$1,662	$1,634	$1,718	$1,844	$2,158	$2,155	$2,376	$2,224	$2,118	$3,286	$4,801	$4,995	$5,187	$5,842	$6,191	$9,821
Export	1,776	1,789	1,876	2,009	2,364	2,403	2,675	2,802	3,287	3,383	3,826	3,836	4,133	5,749	8,819	8,691	9,959	10,812	12,618	17,306
Import	821	738	772	715	702	769	957	958	1,129	1,228	1,450	1,612	2,015	2,463	4,018	3,696	4,772	4,970	6,427	7,485
Machinery[3]																				
Balance	3,752	4,179	4,493	4,648	5,211	5,135	4,991	5,180	5,072	5,567	6,311	5,780	5,646	7,438	12,507	17,245	16,667	13,794	13,358	17,384
Export	4,476	4,968	5,448	5,702	6,525	7,935	7,678	8,279	8,844	10,137	11,685	11,839	13,562	17,588	24,318	29,215	32,113	32,630	38,110	45,914
Import	724	789	955	1,054	1,314	1,800	2,687	3,099	3,772	4,570	5,374	6,059	7,916	10,150	11,811	11,970	15,446	18,836	24,752	28,530
Aircraft																				
Balance	970	766	857	726	791	990	824	1,271	2,015	2,140	2,382	3,049	2,580	3,556	3,258	5,617	5,670	5,271	7,566	8,641
Export	1,024	903	980	817	874	1,130	1,097	1,519	2,309	2,423	2,656	3,387	2,995	4,119	5,766	6,136	6,104	5,874	8,203	9,719
Import	54	137	123	91	83	140	273	248	294	283	274	338	415	563	508	519	434	603	637	1,078
Professional and scientific instruments[4]																				
Balance	214	241	266	290	306	389	463	522	530	609	653	674	668	822	1,308	1,487	1,439	2,200	2,451	3,424
Export	321	358	411	447	504	610	724	807	872	1,012	1,107	1,166	1,313	1,632	2,209	2,397	2,654	4,054	4,977	6,178
Import	107	117	145	157	198	221	261	285	342	403	454	492	645	810	901	910	1,215	1,854	2,526	2,754

[1]Exports less imports.
[2]Includes drugs and other allied products.
[3]Machinery includes all nonelectrical and electrical, computers and communication equipment. Beginning in 1977, sound recorders, reproducers and accessories are classified in machinery (previously included in other manufactured goods) and photocopy apparatus which had previously been in scientific and professional instruments.
[4]Beginning in 1977, includes electric measuring and controlling instruments which were classified as machinery prior to 1977.
SOURCE: Department of Commerce, Domestic and International Business Administration, *Overseas Business Reports*, August 1967, April 1972, April 1977, June 1976, August 1979 and July 1980.

See figure 1-13.

Appendix table 1-26. U.S. trade balance[1] with selected nations for R&D-intensive manufactured products: 1966-79

[Dollars in millions]

Country	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Developing nations[2]														
Balance	$3,441	$3,677	$4,430	$4,455	$4,928	$5,087	5,277	$6,641	$10,658	$14,726	$16,052	$16,022	$17,942	$23,310
Export	3,682	3,923	4,822	5,002	5,679	5,996	6,765	8,966	14,025	17,700	20,104	20,993	24,685	31,510
Import	241	246	392	547	751	909	1,488	2,325	3,367	2,974	4,052	4,971	6,743	8,200
Western Europe[3]														
Balance	1,890	2,283	2,566	2,986	3,942	3,599	3,089	4,126	5,982	6,700	7,061	6,918	10,203	10,042
Export	3,865	4,359	5,020	5,655	6,927	6,861	7,345	9,597	12,621	13,540	14,649	15,712	22,159	24,382
Import	1,975	2,076	2,454	2,669	2,985	3,262	4,256	5,471	6,639	6,840	7,588	8,794	11,956	14,340
Canada														
Balance	1,800	1,760	1,719	1,914	1,684	1,865	2,333	3,003	4,242	4,833	4,732	4,530	4,872	5,420
Export	2,838	2,983	3,142	3,478	3,513	3,914	4,678	5,741	7,419	8,136	8,831	9,182	10,467	12,211
Import	1,038	1,223	1,423	1,564	1,829	2,049	2,345	2,738	3,177	3,303	4,099	4,652	5,595	6,791
Japan														
Balance	−133	−115	−200	−324	−224	−516	−971	−848	−550	−1,020	−2,654	−3,460	−5,694	−4,275
Export	661	772	930	1,180	1,536	1,520	1,639	2,218	3,007	2,390	2,701	2,792	3,630	5,318
Import	794	887	1,130	1,504	1,760	2,036	2,610	3,066	3,557	3,410	5,355	6,252	9,324	9,593
West Germany														
Balance	(4)	(4)	(4)	81	287	190	−56	−204	−211	64	58	−73	−351	−49
Export	(4)	(4)	(4)	912	1,277	1,295	1,340	1,579	1,932	2,143	2,346	2,674	3,480	4,299
Import	(4)	(4)	(4)	831	990	1,105	1,396	1,783	2,143	2,079	2,288	2,747	3,831	4,348

[1]Exports less imports.
[2]Includes the Republic of South Africa in 1966 and 1967.
[3]Includes West Germany.
[4]Included in the totals for Western Europe but not separately available.

SOURCE: Department of Commerce Domestic and International Business Administration, *Overseas Business Reports*, May 1972, June 1974, October 1976, December 1979, and October 1980.

See figure 1-14.

Appendix table 1-27. U.S. transfers of innovations[1] to foreign manufacturing subsidiaries and independent licensees, by period of U.S. introduction: 1945-1975

Period of U.S. introduction	Transfers, by number of years following U.S. introduction					
	Less than 2 years after	2 or 3 years after	4 or 5 years after	6 to 9 years after	10 or more years after	Total
1945-1955:						
(94 innovations)						
Via subsidiaries	14	18	11	43	233	319
Via licensees	1	9	28	16	92	146
Subsidiaries as percent of total	93.3	66.7	28.2	72.9	71.7	68.6
1956-1965:						
(70 innovations)						
Via subsidiaries	24	39	21	46	49	179
Via licensees	7	10	15	13	22	67
Subsidiaries as percent of total	77.4	79.6	58.3	78.0	69.0	72.8
1966-1975:						
(57 innovations)						
Via subsidiaries	22	37	21	16	1	97
Via licensees	2	4	10	6	2	24
Subsidiaries as percent of total	91.7	90.2	67.7	72.7	33.3	80.2
Total, 1945-1975:						
(221 innovations)						
Via subsidiaries	60	94	53	105	283	595
Via licensees	10	23	53	35	116	237
Subsidiaries as percent of total	85.7	80.3	50.0	75.0	70.9	71.5

SOURCE: Raymond Vernon and W. H. Davidson, *Foreign Production of Technology-Intensive Products by U.S.-Based Multinational Enterprises,* National Science Foundation 1979, p. 63.

[1]832 transfers abroad of 221 inovations by 32 U.S.-based multinational enterprises after these innovations were introduced in the United States.

See figure 1-15.

Appendix table 1-28. Examples of possible areas of increased scientific cooperation with Western Europe

Biology
- Genetic engineering
- Seed protein development
- Molecular biology
- Biomass utilization
- Enzyme biology
- Biochemical transformations/technology
- Nitrogen fixation
- Tissue and protoplast culture
- Tropical biology

Behavioral and neural sciences
- Neuroscience
- Cognitive development
- Linguistics (phonetics)
- Social psychology
- Visual sciences

Computer sciences
- Software methodology
- Shared data banks
- Computer-aided design
- Fault-tolerant computers
- Large-scale systems
- Control-system design
- Theoretical computer science (semantics, algorithms)

Chemistry
- Inorganic and organometallic catalysis
- Electrochemical synthesis
- Fast reaction kinetics
- Oscillating reactions/dissipative structure
- Excited-state reactions
- Rarefied gas dynamics
- Neutron scattering
- Quantum chemistry and molecular dynamics
- Solid state chemistry
- Colloid chemistry

Earth and ocean sciences
- Genesis of energy and mineral deposits
- Polar geology, geomorphology and glaciology
- Permafrost research
- Marine geology
- Marine geophysics
- Geochemical analysis
- Rock magnetism
- Coastal geologic processes

Engineering
- Combustion
- Thermionics
- Soil mechanics
- MHD
- Heat and mass transfer
- Optical communication
- Coal processing and communication
- Fluidization
- Particulate processing
- Biochemical engineering

Materials sciences
- High voltage electron microscopy
- Raman spectroscopy
- Resonance raman spectroscopy
- Muon decay in solids
- Statistical mechanics
- Electron structure
- Defects in solids
- Ultra low temperature physics
- Corrosion
- Condensed matter
- Synchroton radiation applications

Mathematics
- Algebraic and arithmetic geometry
- Nonlinear differential equations
- Bifurcation theory
- Mathematical organization theory
- Minimal surfaces
- Axiomatic set theory
- Stochastic processes
- Category theory
- Statistical inference

Physics
- Atomic and molecular physics:
  - Plasma physics
  - Quantum electronics
  - Molecular and colliding beams
- Condensed matter physics:
  - Neutron scattering
  - Solid state physics
  - Superconductivity
- Nuclear physics:
  - Accelerator development
- Elementary particle physics:
  - Gravitational wave detectors
- Theoretical physics:
  - Gravitational physics
  - Mathematical physics
  - Atomic structure

Science education
- Developmental psychology
- Learning theory
- Educational television
- Use of computers with children
- Environmental education
- Curriculum modes and materials

Social sciences
- International economics
- Mathematical economics
- Political economy
- Social psychology
- Socio-economic systems
- Family change
- Technological innovation
- Location analysis
- Sociology of law

NOTE: These examples were generated by a survey of NSF program officers. These areas of scientific activity are those in which Western European efforts are thought to be at a level of excellence comparable to that in the United States, or in which achievements were linked to the availability of unusual instrumentation or facilities.

SOURCE: National Science Foundation Advisory Council, "Expanded Scientific Cooperation with Western Europe," Mimeographed, October 26, 1978.

See discussion in the introduction of the "International Interaction and Cooperation" section.

Appendix table 1-29. Doctoral degrees[1] awarded to foreign students as a percent of all doctoral degrees from U.S. universities by field: 1959-79[2]

Field	1959	1963	1967	1971	1975	1979
All fields	11.7	12.3	14.0	14.4	16.2	16.1
Science and engineering	14.8	15.5	17.5	18.7	22.1	21.1
Physical sciences	12.6	14.0	15.7	16.7	22.9	21.0
Physics and astronomy	14.9	14.5	16.9	18.6	27.6	25.7
Chemistry	10.5	12.2	14.6	15.6	19.8	19.7
Earth sciences[3]	17.1	19.9	17.2	14.6	22.1	16.6
Mathematical sciences	13.4	15.2	14.6	17.5	24.3	25.5
Mathematics	NA	NA	NA	NA	NA	26.7
Computer Sciences	NA	NA	NA	NA	NA	21.3
Engineering	24.5	20.8	23.7	29.8	42.1	46.8
Life sciences	17.6	17.5	19.6	18.2	19.5	16.5
Biological sciences	15.5	16.5	16.2	14.3	14.9	12.1
Agriculture and forestry	24.9	21.0	32.4	33.6	37.4	35.2
Social sciences	10.7	11.6	13.5	13.7	13.7	12.9
Psychology	5.5	4.0	4.4	5.6	5.8	4.0
Other social sciences	15.5	17.6	19.9	19.3	20.2	22.4
Nonscience total	6.0	6.5	7.4	8.0	8.7	10.1

[1]Percent of those whose citizenship are known.
[2]Fiscal year of doctorate.
[3]Includes oceanography.

NA = Not available.

SOURCE: National Science Foundation, *Doctorate Record File, Special Tabulations 1958-1979*, 1980.

See figure 1-16.

Science Indicators—1980

Appendix table 1-30. Distribution of foreign students with percentage of all foreign students by field of study, for selected years: 1954/55-1979/80

Field of study	1954/55 Number of students	1954/55 Percentage of year total	1959/60 Number of students	1959/60 Percentage of year total	1964/65 Number of students	1964/65 Percentage of year total	1969/70 Number of students	1969/70 Percentage of year total	1975/76 Number of students	1975/76 Percentage of year total	1978/79 Number of students	1978/79 Percentage of year total	1979/80 Number of students	1979/80 Percentage of year total
Engineering	7,618	22.3	11,279	23.3	18,084	22.0	29,731	22.0	42,000	23.4	76,030	28.8	76,950	26.9
Business/management	2,953	8.6	4,114	8.5	7,116	8.7	15,587	11.6	28,670	16.0	43,500	16.5	46,960	16.4
Natural and life sciences	3,681	10.7	6,261	12.9	11,731	14.3	17,006	12.6	23,910	13.3	24,190	9.2	21,880	7.6
Social sciences	5,041	14.7	6,782	14.0	12,609	15.4	17,272	12.8	20,730	11.6	23,360	8.9	22,530	7.9
Education	1,457	4.3	2,483	5.1	3,999	4.9	7,779	5.8	9,790	5.5	14,790	5.6	12,340	4.3
Mathematics and computer science	436	1.3	1,015	2.1	2,670	3.3	4,400	3.3	9,060	5.1	14,740	5.6	15,390	5.4
Fine and applied arts	1,997	5.8	2,417	5.0	3,946	4.8	6,297	4.7	8,320	4.6	14,120	5.3	14,350	5.0
Humanities	5,502	16.1	6,829	14.1	12,137	14.8	20,211	14.9	15,030	8.4	14,960	5.7	11,340	4.0
Health professions	3,184	9.3	3,685	7.6	4,918	6.0	5,969	4.4	7,180	4.0	12,470	4.7	10,950	3.8
Agriculture	1,199	3.5	1,615	3.3	3,211	3.9	3,667	2.7	5,270	2.9	8,710	3.3	8,750	3.1
Other	566	1.7	482	1.0	607	.7	597	.4	9,380	5.2	17,070	6.4	24,770[1]	8.7
No answer	598	1.7	1,524	3.1	1,017	1.2	6,443	4.8	—	—	—	—	20,130	7.0
TOTAL	34,232	100.0	48,486	100.0	82,045	100.0	134,959	100.0	179,340	100.0	263,940	100.0	286,340	100.0

[1]Includes 12,170 students in a new category called Intensive English Language.

SOURCE: *Open Doors: 1978/79* (Washington D.C.: Institute of International Education, 1980), pp. 18-19, and unpublished data.

See figure 1-17.

Appendix table 1-31. Foreign postdoctoral students in U.S. doctorate-granting institutions: 1977 and 1979

Field of science	1977			1979		
	Number		Percent foreign	Number		Percent foreign
	Total	Foreign		Total	Foreign	
All fields	19,753	6,201	31	18,589	6,075	33
Engineering	1,230	648	53	1,073	663	62
Physical sciences	4,191	1,728	41	4,028	1,992	49
Environmental sciences[1]	388	111	29	329	112	34
Mathematical sciences	145	51	37	203	94	46
Life sciences	13,011	3,526	27	12,089	3,079	25
Psychology	394	38	10	456	34	7
Social sciences	394	99	25	411	101	25

[1]Environmental sciences includes earth sciences, oceanography, and atmospheric sciences.

SOURCE: National Science Foundation, *Graduate Science Education: Student Support Postdoctorals, Fall 1977, Technical Notes and Detailed Statistical Tables* (NSF 78-315), p. 58; and National Science Foundation, *Academic Science: Graduate Enrollment and Support, Fall, 1979.* Detailed statistical table, forthcoming.

See text table 1-14.

Science Indicators—1980

Appendix table 1-32. Index of international cooperative research[1] by field: 1973-79

Field[2]	1973	1974	1975	1976	1977	1978	1979
	Internationally co-authored articles as a percent of all institutionally co-authored articles						
All fields	12.7	13.3	14.0	14.8	15.1	15.4	16.1
Clinical medicine	6.6	6.9	6.8	7.8	7.5	7.7	8.1
Biomedicine	13.7	14.2	15.2	15.7	16.3	16.4	16.9
Biology	15.5	13.6	15.4	17.0	17.0	17.9	18.6
Chemistry	16.3	17.2	17.7	18.1	20.7	20.0	21.5
Physics	22.7	23.7	25.4	25.9	27.5	29.4	27.8
Earth and space sciences	23.1	22.5	24.6	27.7	27.5	28.7	28.7
Engineering and technology	13.2	14.0	15.5	14.0	16.2	17.2	18.2
Mathematics	34.3	39.5	39.8	38.6	37.9	38.8	40.0
	Internationally co-authored articles						
All fields	8,420	9,113	9,737	10,559	11,338	12,317	13,225
Clinical medicine	1,881	2,013	1,989	2,314	2,440	2,709	2,837
Biomedicine	1,454	1,581	1,775	1,862	2,032	2,156	2,395
Biology	723	655	779	853	915	1,007	1,116
Chemistry	1,088	1,241	1,286	1,384	1,546	1,600	1,763
Physics	1,570	1,757	1,933	2,142	2,320	2,548	2,758
Earth and space sciences	647	658	698	830	849	956	1,021
Engineering and technology	584	650	720	626	721	806	803
Mathematics	473	558	557	548	515	535	532
	All institutionally co-authored articles						
All fields	66,105	68,529	69,579	71,220	75,283	79,955	81,894
Clinical medicine	28,617	28,974	29,078	29,564	32,643	35,160	35,097
Biomedicine	10,648	11,117	11,683	11,845	12,436	13,116	14,144
Biology	4,660	4,829	5,073	5,024	5,405	5,620	5,985
Chemistry	6,694	7,224	7,264	7,632	7,485	7,996	8,185
Physics	6,897	7,410	7,601	8,271	8,433	8,661	9,179
Earth and space sciences	2,798	2,920	2,832	2,994	3,085	3,335	3,553
Engineering and technology	4,412	4,642	4,647	4,470	4,437	4,689	4,421
Mathematics	1,379	1,413	1,401	1,420	1,359	1,378	1,330

[1] Obtained by dividing the number of articles which were written by scientists and engineers from more than one country by the total number of articles jointly written by S/E's from different organizations. This index is based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2] See appendix table 1-13 for the subfields included in these fields.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 1-18.

Appendix table 1-33. Index of international cooperative research[1] for selected countries: 1973-79

Country[2]	1973	1974	1975	1976	1977	1978	1979
	Internationally co-authored articles as a percent of all institutionally co-authored articles						
West Germany	35.6	37.3	38.2	40.6	41.3	41.6	43.8
United Kingdom	35.3	37.0	37.7	39.6	40.7	40.2	40.4
Canada	37.0	38.0	37.3	38.5	38.4	39.4	39.9
France	26.7	26.9	29.8	31.4	32.5	33.5	33.9
U.S.S.R.	9.6	10.9	13.3	14.2	17.3	16.3	20.1
United States	14.0	14.3	15.0	15.9	15.9	15.7	16.6
Japan	16.4	16.4	16.1	15.2	15.9	15.5	16.3
	Internationally co-authored articles						
West Germany	1,283	1,527	1,568	1,741	1,923	2,176	2,244
United Kingdom	2,029	2,219	2,364	2,574	2,633	2,784	2,889
Canada	1,302	1,369	1,422	1,532	1,599	1,715	1,812
France	1,131	1,209	1,460	1,591	1,769	1,837	2,003
U.S.S.R.	288	318	380	432	523	528	604
United States	4,807	5,037	5,254	5,675	5,972	6,248	6,755
Japan	472	495	543	555	635	678	767
	All institutionally co-authored articles						
West Germany	3,605	4,093	4,108	4,287	4,654	5,228	5,128
United Kingdom	5,749	6,002	6,268	6,501	6,473	6,925	7,159
Canada	3,521	3,604	3,809	3,976	4,166	4,358	4,543
France	4,233	4,492	4,901	5,065	5,445	5,491	5,902
U.S.S.R.	3,011	2,926	2,860	3,033	3,031	3,233	3,005
United States	34,364	35,338	35,100	35,799	37,618	39,768	40,784
Japan	2,881	3,018	3,363	3,657	3,984	4,386	4,696

[1]Obtained by dividing the number of articles which were written by scientists and engineers from more than one country by the total number of articles jointly written by SIE's from different organizations. This index is based on the articles notes and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2]When an article is authored by scientists and engineers from more than one country, that article is counted once for each country involved. For example if a given article has several authors from France and the United States, it is split to France and to the United States regardless of the in proportion to the number of actual authors from these countries.

SOURCE: Computer Horizons Inc., unpublished data.

See figure 1–19.

Appendix table 1-34. Distribution of scientific and technical articles[1] in U.S. and foreign journals by field: 1973-79

Field[2]	1973	1974	1975	1976	1977	1978	1979
				U.S. articles[3] in foreign journals[4]			
All fields	19,157	19,176	18,913	19,463	19,373	20,365	20,060
Clinical medicine	4,695	4,850	5,000	4,854	4,975	5,384	5,268
Biomedicine	4,124	4,092	4,098	4,544	4,306	4,720	4,896
Biology	1,660	1,711	1,999	2,180	2,049	2,006	2,037
Chemistry	2,346	2,342	2,107	1,970	2,018	2,168	2,036
Physics	2,661	2,702	2,513	2,516	2,742	2,535	2,525
Earth and space sciences	1,200	1,131	996	1,109	1,126	1,152	1,179
Engineering and technology	1,382	1,338	1,195	1,255	1,302	1,565	1,351
Mathematics	1,089	1,010	1,005	1,035	855	835	768
				Foreign articles in U.S. journals			
All fields	28,425	28,902	30,425	32,502	33,058	33,860	36,353
Clinical medicine	6,794	6,867	6,882	7,560	7,923	8,398	8,898
Biomedicine	4,148	4,340	5,144	5,154	5,377	5,158	5,493
Biology	2,013	1,889	1,865	1,803	1,971	2,296	2,587
Chemistry	5,484	5,700	6,270	7,062	6,583	6,252	6,769
Physics	4,118	4,384	4,434	5,048	5,143	5,556	6,095
Earth and space sciences	1,284	1,204	1,108	1,170	1,146	1,283	1,251
Engineering and technology	3,723	3,611	3,748	3,618	3,848	3,904	4,241
Mathematics	861	907	974	1,087	1,067	1,013	1,019
				Balance[5]			
All fields	9,268	9,726	11,512	13,039	13,685	13,495	16,293
Clinical medicine	2,099	2,017	1,882	2,706	2,948	3,014	3,630
Biomedicine	24	248	1,046	610	1,071	438	597
Biology	353	178	−134	−377	−78	290	550
Chemistry	3,138	3,358	4,163	5,092	4,565	4,084	4,733
Physics	1,457	1,682	1,921	2,532	2,401	3,021	3,570
Earth and space sciences	84	73	112	61	20	131	72
Engineering and technology	2,341	2,273	2,553	2,363	2,546	2,339	2,890
Mathematics	−228	−103	− 31	52	212	178	251

[1]Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* corporate tapes of the Institute for Scientific Information. For the size of this data base, see Appendix table 1-12.

[2]See Appendix table 1-13 for a description of the subfields included in these fields. Note that because psychology journals began to be removed from the *SCI* in 1978 for inclusion in the *Social Sciences Citation index*, the "All fields" totals for all years exclude psychology articles.

[3]When an article is written by researchers from more than one country, that article is prorated across the countries involved. For example, if a given article has several authors from France and the United States, it is split to these countries on the basis of the number of organizations represented by these authors.

[4]The country of a journal is determined by where it is published.

[5]When the balance in negative, more U.S. articles are being published in journals abroad than foreign articles in U.S. journals. When the balance is positive, the United States is publishing more foreign articles than U.S. researchers are publishing abroad.

SOURCE: Computer Horizons, Inc., unpublished data.

See table 1-16 in text.

Science Indicators—1980

Appendix table 1-35. Index[1] of U.S. utilization of domestic and foreign scientific and technical literature:[2] 1973 and 1979

Field[3]		United States	Non-U.S. Countries Total	United Kingdom	West Germany	France	U.S.S.R.	Japan	Canada
Clinical medicine	1973	1.50	0.63	1.06	0.29	0.30	0.06	0.56	1.13
	1979	1.43	.68	1.04	.47	.45	.07	.65	1.03
	Diff.	−.07	.05	−.02	.18	.15	.01	.09	−.10
Biomedicine	1973	1.49	.68	1.17	.60	.46	.09	.78	.97
	1979	1.37	.75	1.00	.91	.69	.14	.90	1.00
	Diff.	−.12	.07	−.17	.31	.23	.05	.12	.03
Biology	1973	1.36	.69	.95	.57	.43	.19	.44	.93
	1979	1.38	.72	.95	.64	.63	.21	.49	.99
	Diff.	.02	.03	.00	.07	.20	.02	.05	.06
Chemistry	1973	1.94	.72	1.42	1.20	.67	.14	.59	1.46
	1979	1.95	.74	1.49	1.20	.92	.15	.72	1.41
	Diff.	.01	.02	.07	.00	.25	.01	.13	−.05
Physics	1973	1.60	.71	.96	.98	.88	.30	.63	1.25
	1979	1.53	.77	1.13	1.06	.94	.28	.82	1.18
	Diff.	−.07	.06	.17	.08	.06	−.02	.19	−.07
Earth & space sciences	1973	1.38	.67	1.07	.73	.58	.20	.62	1.01
	1979	1.42	.66	.91	.71	.71	.16	.78	.86
	Diff.	.04	−.01	−.16	−.02	.13	−.04	.16	−.15
Engineering & technology	1973	1.44	.68	1.01	.46	.74	.15	.64	1.21
	1979	1.37	.75	1.12	.54	.72	.20	.93	1.03
	Diff.	−.07	.07	.11	.08	−.02	.05	.29	−.18
Mathematics	1973	1.25	.77	1.15	.72	.59	.92	.60	.81
	1979	1.38	.74	1.20	.60	.59	.43	.64	1.05
	Diff.	.38	−.03	.05	−.12	.00	−.49	.04	.24

[1]An index of 1.00 reflects no over- or under-citing of the U.S. scientific and technical literature, whereas a higher ratio indicates a greater influence, impact or utility than would have been expected from the number of a country's articles. For example, West German chemical literature for 1979 received 20 percent more citations in the U.S. literature than could be accounted for by the West German share of the world's chemical literature.

[2]Based on the articles, notes and reviews in over 2,100 of the influential journals carried on the *Science Citation Index* Corporate tapes of the Institute for Scientific Information. For the size of this data based, see Appendix table 1-12.

[3]See appendix table 1-13 for a description of the subfields included in these fields.

See figure 1-20.

Science Indicators—1980

Appendix table 2-1. Gross National Product price deflators used in the calculation of 1972 constant dollars throughout this report

Year	Calendar year GNP price deflator	Fiscal year GNP price deflator
1953	.5882	.5968
1960	.6870	.6957
1961	.6933	.7036
1962	.7061	.7137
1963	.7167	.7256
1964	.7277	.7338
1965	.7436	.7498
1966	.7676	.7696
1967	.7906	.7944
1968	.8254	.8231
1969	.8679	.8617
1970	.9145	.9104
1971	.9601	.9562
1972	1.0000	1.0000
1973	1.0569	1.0443
1974	1.1492	1.1194
1975	1.2556	1.2306
1976	1.3211	1.3165
1977	1.3983	1.4055
1978	1.5005	1.4996
1979	1.6277	1.6284
1980	1.7736	1.7672
1981	1.9492	1.9439

NOTE: Calendar year deflators were taken directly from sources cited below. Fiscal year deflators were calculated from quarterly data in the same sources.

SOURCE: Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business*, and "*Commerce News*."

Science Indicators — 1980

Appendix table 2-2. National R & D expenditures: 1960-81

[Dollars in billions]

Year	Current dollars	Constant 1972 dollars[1]
1960	$13.5	$19.6
1961	14.3	20.6
1962	15.4	21.8
1963	17.1	23.7
1964	18.9	25.9
1965	20.0	26.9
1966	21.8	28.4
1967	23.1	29.2
1968	24.6	29.8
1969	25.6	29.6
1970	26.1	28.5
1971	26.7	27.8
1972	28.4	28.4
1973	30.7	29.1
1974	32.8	28.8
1975	35.2	28.2
1976	38.9	29.5
1977	42.9	30.7
1978	48.0	32.0
1979 (prelim)	54.2	33.3
1980 (est)	61.1	34.5
1981 (est)	69.1	35.5

[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), and unpublished data.

See figure 2-1.

Science Indicators — 1980

Appendix table 2-3. National R & D expenditures as a percent of GNP by source: 1960-81

[Dollars in billions]

Year	Current dollars: GNP	Current dollars: All R&D by source: Total	Current dollars: All R&D by source: Federal	Current dollars: All R&D by source: Other	Current dollars: Basic & Applied	Constant 1972 dollars[1]: GNP	Constant 1972 dollars[1]: All R&D by source: Total	Constant 1972 dollars[1]: All R&D by source: Federal	Constant 1972 dollars[1]: All R&D by source: Other	Constant 1972 dollars[1]: Basic & Applied	As a percent of GNP: All R&D by source: Total	As a percent of GNP: All R&D by source: Federal	As a percent of GNP: All R&D by source: Other	As a percent of GNP: Basic & applied research
1960	$ 506.5	$13.5	$ 8.7	$ 4.8	$ 4.2	$ 737.3	$19.6	$12.7	$ 7.0	$ 6.1	2.67	1.72	0.95	0.83
1961	524.6	14.3	9.3	5.0	4.5	756.7	20.6	13.3	7.2	6.4	2.73	1.77	.95	.86
1962	565.0	15.4	9.9	5.5	5.4	800.2	21.8	14.0	7.8	7.6	2.73	1.75	.97	.96
1963	596.7	17.1	11.2	5.9	5.7	832.6	23.7	15.6	8.2	7.9	2.87	1.88	.99	.96
1964	637.7	18.9	12.5	6.3	6.4	876.3	25.9	17.2	8.7	8.8	2.96	1.96	.99	1.00
1965	691.1	20.0	13.0	7.0	6.9	929.4	26.9	17.4	9.5	9.2	2.89	1.88	1.01	1.00
1966	756.0	21.8	14.0	7.9	7.4	984.9	28.4	18.2	10.2	9.6	2.88	1.85	1.05	.98
1967	799.6	23.1	14.4	8.8	7.8	1,011.4	29.2	18.2	11.1	9.9	2.89	1.80	1.10	.98
1968	873.4	24.6	14.9	9.7	8.4	1,058.2	29.8	18.1	11.7	10.2	2.82	1.71	1.11	.96
1969	944.0	25.6	14.9	10.7	8.8	1,087.7	29.6	17.2	12.4	10.1	2.71	1.58	1.13	.93
1970	992.7	26.1	14.8	11.3	9.2	1,085.5	28.5	16.2	12.3	10.1	2.63	1.49	1.14	.93
1971	1,077.6	26.7	14.9	11.8	9.4	1,122.4	27.8	15.6	12.2	9.8	2.48	1.38	1.10	.87
1972	1,185.9	28.4	15.8	12.6	9.8	1,185.9	28.4	15.8	12.7	9.8	2.40	1.33	1.06	.83
1973	1,326.4	30.7	16.3	14.4	10.5	1,255.0	29.1	15.6	13.5	10.0	2.32	1.23	1.09	.79
1974	1,434.2	32.8	16.8	16.0	11.4	1,248.0	28.8	14.8	14.0	10.0	2.29	1.17	1.12	.80
1975	1,549.2	35.2	18.1	17.1	12.4	1,233.8	28.2	14.5	13.7	10.0	2.27	1.17	1.10	.80
1976	1,718.0	38.9	19.8	19.1	13.9	1,300.4	29.5	15.0	14.5	10.6	2.26	1.15	1.11	.81
1977	1,918.0	42.9	21.7	21.2	15.3	1,371.7	30.7	15.5	15.2	10.9	2.24	1.13	1.11	.80
1978	2,156.1	48.0	23.9	24.1	17.2	1,436.9	32.0	15.9	16.1	11.4	2.23	1.11	1.11	.80
1979 (prelim) ...	2,413.9	54.2	26.6	27.6	19.4	1,483.0	33.3	16.3	17.0	11.9	2.25	1.10	1.14	.80
1980 (est)	2,626.1	61.1	29.3	31.8	21.9	1,480.7	34.5	16.6	17.9	12.3	2.33	1.12	1.21	.83
1981 (est)	2,920.0	69.1	32.7	36.4	24.1	1,498.1	35.5	16.8	18.7	12.4	2.37	1.12	1.25	.83

[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: Percents are calculated from unrounded figures. Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), and unpublished data, and Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business,* and *Commerce News.*

See figures 2-2, and 2-3.

Appendix table 2-4. National expenditures for R & D by source: 1960-81

[Dollars in millions]

Year	Total	Federal Government	Industry	Universities and colleges[1]	Other nonprofit institutions
			Current dollars		
1960	$13,523	$ 8,738	$ 4,516	$ 149	$ 120
1961	14,316	9,250	4,757	165	144
1962	15,394	9,911	5,123	185	175
1963	17,059	11,204	5,456	207	192
1964	18,854	12,537	5,887	235	195
1965	20,044	13,012	6,548	267	217
1966	21,846	13,968	7,328	304	246
1967	23,146	14,395	8,142	345	264
1968	24,605	14,928	9,005	390	282
1969	25,631	14,895	10,010	420	306
1970	26,072	14,830	10,444	461	337
1971	26,653	14,941	10,822	529	361
1972	28,429	15,760	11,710	574	385
1973	30,665	16,346	13,293	613	413
1974	32,814	16,800	14,878	677	459
1975	35,169	18,065	15,820	749	535
1976	38,935	19,833	17,694	808	600
1977	42,923	21,674	19,696	881	672
1978	48,023	23,893	22,336	1,028	766
1979 (prelim)	54,215	26,556	25,638	1,183	838
1980 (est)	61,127	29,302	29,475	1,385	965
1981 (est)	69,065	32,665	33,865	1,485	1,050
			Constant 1972 dollars[2]		
1960	$19,635	$12,673	$ 6,573	$ 214	$175
1961	20,584	13,282	6,861	235	206
1962	21,750	13,989	7,256	259	246
1963	23,733	15,570	7,611	285	267
1964	25,857	17,179	8,090	320	268
1965	26,896	17,443	8,806	356	291
1966	28,442	18,180	9,547	395	320
1967	29,241	18,176	10,299	434	332
1968	29,833	18,108	10,910	474	341
1969	29,586	17,209	11,536	488	353
1970	28,545	16,248	11,421	506	370
1971	27,790	15,591	11,271	553	375
1972	28,429	15,760	11,710	574	385
1973	29,112	15,551	12,579	588	394
1974	28,755	14,798	12,947	605	405
1975	28,169	14,526	12,603	608	432
1976	29,499	15,038	13,393	613	455
1977	30,654	15,464	14,085	626	479
1978	32,010	15,928	14,886	685	511
1979 (prelim)	33,304	16,312	15,751	727	514
1980 (est)	34,499	16,551	16,619	784	545
1981 (est)	35,457	16,781	17,373	763	540

[1]Includes State and local sources which have accounted for almost one-half of these expenditures since 1970.

[2]GNP implicit deflators used to convert current dollars to constant 1972 dollars.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resourses, 1980* (NSF 80-308), and unpublished data.

See figure 2-4.

Appendix table 2-5. National expenditures for R & D by performer: 1960-81

[Dollars in millions]

Year	Total	Federal Government	Industry	Universities and colleges[1]	FFRDC's[2]	Other nonprofit institutions
			Current dollars			
1960	$13,523	$1,726	$10,509	$ 646	$ 360	$ 282
1961	14,316	1,874	10,908	763	410	361
1962	15,394	2,098	11,464	904	470	458
1963	17,059	2,279	12,630	1,081	530	539
1964	18,854	2,838	13,512	1,275	629	600
1965	20,044	3,093	14,185	1,474	629	663
1966	21,846	3,220	15,548	1,715	630	733
1967	23,146	3,396	16,385	1,921	673	771
1968	24,605	3,494	17,429	2,149	719	814
1969	25,631	3,503	18,308	2,225	725	870
1970	26,072	4,017	18,067	2,335	737	916
1971	26,653	4,205	18,320	2,500	716	912
1972	28,429	4,542	19,552	2,630	753	952
1973	30,665	4,709	21,249	2,884	817	1,006
1974	32,814	4,861	22,887	3,023	865	1,178
1975	35,169	5,310	24,187	3,409	987	1,276
1976	38,935	5,688	26,997	3,727	1,147	1,376
1977	42,923	6,053	29,928	4,063	1,384	1,495
1978	48,023	6,856	33,164	4,614	1,717	1,672
1979 (prelim)	54,215	7,497	37,606	5,183	1,935	1,994
1980 (est)	61,127	8,052	42,750	5,950	2,200	2,175
1981 (est)	69,065	8,965	49,150	6,300	2,300	2,350
			Constant 1972 dollars[3]			
1960	$19,635	$2,481	$15,297	$ 928	$ 517	$ 412
1961	20,584	2,664	15,733	1,085	582	520
1962	21,750	2,940	16,237	1,266	659	648
1963	23,733	3,140	17,622	1,489	730	752
1964	25,857	3,868	18,569	1,738	857	825
1965	26,896	4,124	19,077	1,965	838	892
1966	28,442	4,183	20,256	2,229	819	955
1967	29,241	4,276	20,725	2,417	848	975
1968	29,833	4,246	21,116	2,612	874	985
1969	29,586	4,065	21,094	2,582	842	1,003
1970	28,545	4,413	19,756	2,564	809	1,003
1971	27,790	4,398	19,081	2,613	749	949
1972	28,429	4,542	19,552	2,630	753	952
1973	29,112	4,510	20,106	2,763	782	951
1974	28,755	4,342	19,915	2,700	773	1,025
1975	28,169	4,315	19,263	2,771	802	1,018
1976	29,499	4,321	20,435	2,831	871	1,041
1977	30,654	4,307	21,403	2,890	985	1,069
1978	32,010	4,572	22,103	3,076	1,145	1,114
1979 (prelim)	33,304	4,604	23,104	3,182	1,188	1,226
1980 (est)	34,499	4,556	24,103	3,367	1,245	1,228
1981 (est)	35,457	4,612	25,216	3,239	1,183	1,207

[1]Includes State and local sources.
[2]Federally Funded Research and Development Centers administered by universities.
[3]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), and upublished data.

See figure 2-5.

Appendix table 2-6. Scientists and engineers[1] employed in R&D by sector: 1961-80

[In thousands]

Year	Total	Federal Government	Industry	Universities and colleges	FFRDC's[2]	Other nonprofit institutions
1961	425.7	51.1	312.0	42.4	9.1	11.1
1965	494.5	61.8	348.4	53.4	11.1	19.9
1968	550.4	68.1	381.9	66.0	11.2	23.2
1969	555.2	68.5	385.6	68.3	11.6	21.2
1970	546.5	69.8	375.5	68.5	11.5	21.2
1971	526.4	66.5	358.4	68.4	11.5	21.6
1972	518.3	64.4	353.9	66.5	11.7	21.8
1973	518.4	61.8	358.8	63.5	12.0	22.3
1974	525.1	62.6	361.6	65.5	12.1	23.3
1975	534.9	63.4	363.8	70.2	12.7	24.8
1976	549.2	64.0	373.6	71.8	13.4	26.4
1977	573.9	64.7	393.2	74.5	14.0	27.5
1978 (prelim)	601.6	65.4	415.8	77.7	14.7	28.0
1979 (est)	629.5	66.0	440.0	80.0	15.0	28.5
1980 (est)	659.0	66.5	465.0	82.5	16.0	29.0

[1]Full-time-equivalent basis, excluding those employed in State and local agencies, and calculated as the yearly average for the industry sector.
[2]Federally Funded Research and Development Centers administered by universities.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), and unpublished data.

See figure 2-6.

Science Indicators—1980

Appendix table 2-7. Percent change in the number of science and technology articles[1] by U.S. authors by field: 1973-79

Field[2]	Number of articles 1973	1974	1975	1976	1977	1978	1979	Percent change (1973 to 1979)
All fields	103,793	100,075	96,563	99,430	97,484	99,214	99,384	−4
Clinical medicine	32,565	31,253	30,720	32,821	33,425	34,968	33,978	4
Biomedicine	16,122	15,607	15,865	16,259	16,186	16,611	17,649	9
Biology	11,152	10,700	10,106	10,573	9,904	9,663	10,553	−5
Chemistry	10,635	10,307	9,750	9,433	8,976	9,266	9,182	−14
Physics	11,736	11,945	11,266	11,499	10,987	11,015	10,995	−7
Earth and space sciences	5,591	5,371	4,766	5,009	4,810	5,043	5,167	−8
Engineering and technology	11,954	11,087	10,430	10,345	10,078	9,694	9,017	−25
Mathematics	4,128	3,797	3,652	3,484	3,112	2,949	2,838	−32

[1]Based on articles, notes and reviews from over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.
[2]See appendix table 1-13 for the subfields included in these totals.

NOTE: Detail may not add to totals because of rounding. Likewise, counts of articles may differ slightly from those of other tables in this report, for technical reasons.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 2-7

Science Indicators—1980

Appendix table 2-8. Distribution of scientific and technical articles[1] written by U.S. scientists and engineers by field and research sector: 1973 and 1979

Field[2]	Year	Total	Universities and colleges	Federal Gov't	Industry[3]	Nonprofit institutions[3]	FFRDC's[4]	All others
					Number of articles			
All fields	1973	103,788	67,575	11,415	10,933	7,131	3,275	3,459
	1979	99,379	67,173	10,379	8,601	6,821	2,848	3,557
Clinical medicine	1973	32,565	20,781	3,801	1,310	4,749	186	1,738
	1979	33,978	22,758	3,942	1,077	4,596	104	1,501
Biomedicine	1973	16,120	12,320	1,530	506	1,123	327	314
	1979	17,649	13,711	1,654	460	1,193	234	397
Biology	1973	11,151	7,733	2,188	384	377	53	416
	1979	10,553	7,661	1,790	308	352	48	394
Chemistry	1973	10,566	7,235	792	1,847	202	361	129
	1979	9,182	6,363	681	1,510	177	261	190
Physics	1973	11,710	7,238	1,032	1,706	150	1,308	276
	1979	10,995	6,844	771	1,654	151	1,164	411
Earth and space science	1973	5,591	3,769	883	281	170	383	105
	1979	5,167	3,526	758	300	141	301	141
Engineering and technology	1973	11,954	4,716	1,080	4,789	294	623	452
	1979	9,017	3,711	718	3,212	162	904	510
Mathematics	1973	4,126	3,782	109	109	66	32	28
	1979	2,838	2,599	65	80	49	32	13
					Percent			
All fields	1973	100	65	11	11	7	3	3
	1979	100	68	10	9	7	3	4
Clinical medicine	1973	100	64	12	4	15	1	5
	1979	100	67	12	3	14	0	4
Biomedicine	1973	100	76	9	3	7	2	2
	1979	100	78	9	3	7	1	2
Biology	1973	100	69	20	3	3	0	4
	1979	100	73	17	3	3	0	4
Chemistry	1973	100	68	7	17	2	3	1
	1979	100	69	7	16	2	3	2
Physics	1973	100	62	9	15	1	11	2
	1979	100	62	7	15	1	11	4
Earth and space science	1973	100	67	16	5	3	7	2
	1979	100	68	15	6	3	6	3
Engineering and technology	1973	100	39	9	40	2	10	6
	1979	100	41	8	36	2	5	4
Mathematics	1973	100	92	3	3	2	1	1
	1979	100	92	2	2	2	1	([3])

[1]Based on the articles, notes and reviews by U. S. authors in over 2,100 of the influential journals on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.
[2]See appendix table 1-13 for the subfields included in those fields.
[3]Excluding the Federally Funded Research and Development Centers (FFRDC's) administered by these sectors.
[4]FFRDC's administered by universities.
[5]Less than 0.5 percent.

NOTE: Detail may not add to the totals because of rounding. Likewise, counts of articles may differ slightly from those of other tables in this report, for technical reasons.

SOURCE: Computer Horizons, Inc., unpublished data.

Appendix table 2-9. Index[1] of cooperative research based on scientific and technical articles[2] by field and selected research-performing sectors: 1973 and 1979

Fields	Universities and colleges 1973	Universities and colleges 1979	Federal Government 1973	Federal Government 1979	Industry[3] 1973	Industry[3] 1979	Nonprofit[3] institutions 1973	Nonprofit[3] institutions 1979	FFRDC's[4] 1973	FFRDC's[4] 1979
All fields	39	46	45	57	24	32	59	65	45	50
Clinical medicine	54	59	61	72	38	46	65	70	51	53
Biomedicine	38	44	47	56	35	46	56	62	50	53
Biology	29	35	34	44	29	46	40	43	47	48
Chemistry	23	29	24	30	17	20	36	47	53	52
Physics	37	44	28	42	24	31	41	46	48	55
Earth and space sciences	37	46	42	49	43	46	47	47	47	63
Engineering and technology	32	39	29	41	19	27	25	41	28	28
Mathematics	23	29	24	37	36	44	49	61	([5])	([5])

[1]Consisting of the percentage of all articles which were written by scientists and engineers in a given organization with those from another organization: e.g., if S/E's from one university co-author an article with S/E's from another university or corporation, it is assumed here that there was some degree of cooperative research performed.
[2]Based on articles, notes and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.
[3]Excluding the Federally Funded Research and Development Centers administered by this sector.
[4]FFRDC's administered by universities.
[5]Because the total number of articles was less than 50, no index percentages are calculated.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 2-8.

Science Indicators — 1980

Appendix table 2-10. Research and development expenditures: 1960-81

[Dollars in millions]

Year	Research total: Current dollars	Research total: Constant 1972 dollars[1]	Development total: Current dollars	Development total: Constant 1972 dollars[1]
1960	$ 4,217	$ 6,109	$ 9,306	$13,526
1961	4,466	6,403	9,850	14,181
1962	5,389	7,602	10,005	14,148
1963	5,707	7,921	11,352	15,812
1964	6,417	8,787	12,437	17,070
1965	6,894	9,234	13,150	17,662
1966	7,415	9,649	14,431	18,793
1967	7,836	9,889	15,310	19,352
1968	8,427	10,224	16,178	19,609
1969	8,757	10,124	16,874	19,462
1970	9,222	10,108	16,850	18,437
1971	9,418	9,828	17,235	17,962
1972	9,766	9,766	18,663	18,663
1973	10,512	10,007	20,153	19,105
1974	11,418	10,065	21,396	18,690
1975	12,446	10,016	22,723	18,153
1976	13,925	10,559	25,010	18,940
1977	15,269	10,891	27,654	19,763
1978	17,156	11,437	30,867	20,573
1979 (prelim)	19,361	11,892	34,854	21,412
1980 (est)	21,858	12,348	39,269	22,151
1981 (est)	24,062	12,361	45,003	23,096

[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), and unpublished data.

See figure 2-9.

Science Indicators — 1980

Appendix table 2-11. Total research expenditures by source: 1960-81

[Dollars in millions]

Year	Total	Federal Government	Industry	Universities and colleges	Nonprofit institutions
	Current dollars				
1960	$ 4,217	$ 2,403	$1,568	$ 138	$108
1961	4,466	2,628	1,556	154	128
1962	5,389	3,198	1,864	172	155
1963	5,707	3,436	1,908	193	170
1964	6,417	3,995	2,026	221	175
1965	6,894	4,333	2,115	252	194
1966	7,415	4,560	2,351	286	218
1967	7,836	4,895	2,381	325	235
1968	8,427	5,146	2,660	373	248
1969	8,757	5,226	2,860	403	268
1970	9,222	5,522	2,955	448	297
1971	9,418	5,544	3,041	515	318
1972	9,766	5,690	3,178	555	343
1973	10,512	6,072	3,496	580	364
1974	11,418	6,397	3,983	635	403
1975	12,446	7,054	4,222	702	468
1976	13,925	7,874	4,772	756	523
1977	15,269	8,589	5,274	823	583
1978	17,156	9,632	5,916	950	658
1979 (prelim)	19,361	10,767	6,775	1,103	716
1980 (est)	21,858	11,978	7,755	1,295	830
1981 (est)	24,062	12,872	8,900	1,385	905
	Constant 1972 dollars[1]				
1960	$ 6,109	$3,472	$2,282	$198	$157
1961	6,403	3,757	2,244	219	183
1962	7,602	4,503	2,640	241	218
1963	7,921	4,758	2,661	266	236
1964	8,787	5,462	2,784	301	240
1965	9,234	5,794	2,844	336	260
1966	9,649	5,930	3,063	372	284
1967	9,889	6,172	3,012	409	296
1968	10,224	6,248	3,223	453	300
1969	10,124	6,050	3,297	468	309
1970	10,108	6,058	3,232	492	326
1971	9,828	5,792	3,167	538	331
1972	9,766	5,690	3,178	555	343
1973	10,007	5,795	3,309	556	347
1974	10,065	5,676	3,467	567	355
1975	10,016	5,703	3,365	570	378
1976	10,559	5,976	3,612	574	397
1977	10,891	6,119	3,771	585	416
1978	11,437	6,422	3,943	633	439
1979 (prelim)	11,892	6,613	4,162	678	439
1980 (est)	12,348	6,773	4,373	733	469
1981 (est)	12,361	6,618	4,566	712	465

[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), and unpublished data.

See figure 2-10.

Appendix table 2-12. National R & D expenditures by character of work: 1960-81

[Dollars in millions]

Year	Current dollars			Constant 1972 dollars[1]		
	Basic research	Applied research	Development	Basic research	Applied research	Development
1960	$1,197	$ 3,020	$ 9,306	$1,729	$4,380	$13,526
1961	1,401	3,065	9,850	2,004	4,399	14,181
1962	1,724	3,665	10,005	2,427	5,175	14,148
1963	1,965	3,742	11,352	2,720	5,201	15,812
1964	2,289	4,128	12,437	3,129	5,658	17,070
1965	2,555	4,339	13,150	3,416	5,818	17,662
1966	2,814	4,601	14,431	3,660	5,989	18,793
1967	3,056	4,780	15,310	3,853	6,036	19,352
1968	3,296	5,131	16,178	4,001	6,223	19,609
1969	3,441	5,316	16,874	3,985	6,139	19,462
1970	3,496	5,726	16,850	3,837	6,271	18,437
1971	3,630	5,788	17,235	3,792	6,036	17,962
1972	3,788	5,978	18,663	3,788	5,978	18,663
1973	3,924	6,588	20,153	3,745	6,262	19,105
1974	4,207	7,211	21,396	3,732	6,333	18,690
1975	4,575	7,871	22,723	3,700	6,316	18,153
1976	4,928	8,997	25,010	3,740	6,819	18,940
1977	5,485	9,784	27,654	3,906	6,985	19,763
1978	6,318	10,838	30,867	4,211	7,226	20,573
1979 (prelim)	7,164	12,197	34,854	4,400	7,492	21,412
1980 (est) ...	8,132	13,726	39,269	4,599	7,749	22,151
1981 (est) ...	8,772	15,290	45,003	4,510	7,851	23,096

[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: The following definitions apply to the character of work categories presented above.

Basic research. For three of the sectors — Federal Government, universities and colleges, and other nonprofit institutions — the definition of basic research is directed toward increases of knowledge in science with "... a fuller knowledge or understanding of the subject under study, rather than a practical application thereof." To take account of an individual industrial company's commercial goals, the definition for the industry sector is modified to indicate that basic research projects represent "... original investigations for the advancement of scientific knowledge ... which do not have specific commerical objectives, although they may be in fields of present or potential interest to the reporting company."

Applied Research. The following is the core definition in the NSF questionnaire sent to the universities and colleges: "Applied research is directed toward practical application of knowledge." Here again, the definition for the industry survey takes account of the characteristics of industrial organizations. It covers "... research projects which represent investigations directed to discovery of new scientific knowledge and which have specific commercial objectives with respect to either products or processes."

Development. The NSF survey's concept of development may be summarized as "... the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems or methods, including design and development of prototypes and processes."

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), and unpublished data.

See figure 2-11.

Science Indicators — 1980

Appendix table 2-13. Basic research expenditures by source: 1960-81

[Dollars in millions]

Year	Total	Federal Government	Industry	Universities and colleges	Other nonprofit institutions
			Current dollars		
1960	$1,197	$ 715	$ 342	$ 72	$ 68
1961	1,401	874	361	85	81
1962	1,724	1,131	394	102	97
1963	1,965	1,311	425	121	108
1964	2,289	1,598	433	144	114
1965	2,555	1,809	461	164	121
1966	2,814	1,978	510	197	129
1967	3,056	2,201	492	223	140
1968	3,296	2,336	535	276	149
1969	3,441	2,441	540	298	162
1970	3,496	2,436	528	350	182
1971	3,630	2,487	547	400	196
1972	3,788	2,592	563	415	218
1973	3,924	2,687	605	408	224
1974	4,207	2,880	651	432	244
1975	4,575	3,106	705	478	286
1976	4,928	3,388	769	474	297
1977	5,485	3,778	850	519	338
1978	6,318	4,382	962	596	378
1979 (prelim)	7,164	4,937	1,112	703	412
1980 (est)	8,132	5,557	1,265	825	485
1981 (est)	8,772	5,922	1,445	885	520
			Constant 1972 dollars[1]		
1960	$1,729	$1,030	$497	$103	$ 99
1961	2,004	1,246	521	121	116
1962	2,427	1,590	558	143	136
1963	2,720	1,811	592	167	150
1964	3,129	2,182	595	196	156
1965	3,416	2,415	620	219	162
1966	3,660	2,571	665	256	168
1967	3,853	2,774	622	281	176
1968	4,001	2,837	649	335	180
1969	3,985	2,829	623	346	187
1970	3,837	2,675	578	384	200
1971	3,792	2,600	570	418	204
1972	3,788	2,592	563	415	218
1973	3,745	2,568	573	391	213
1974	3,732	2,564	567	386	215
1975	3,700	2,518	563	388	231
1976	3,740	2,573	582	360	225
1977	3,906	2,689	607	369	241
1978	4,211	2,921	641	397	252
1979 (prelim)	4,400	3,032	683	432	253
1980 (est)	4,599	3,144	714	467	274
1981 (est)	4,510	3,046	742	455	267

[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), and unpublished data.

See figure 2-12.

Appendix table 2-14. Applied research expenditures by source: 1960-81

[Dollars in millions]

Year	Total	Federal Government	Industry	Universities and colleges	Other nonprofit institutions
			Current dollars		
1960	$ 3,020	$1,688	$1,226	$ 66	$ 40
1961	3,065	1,754	1,195	69	47
1962	3,665	2,067	1,470	70	58
1963	3,742	2,125	1,483	72	62
1964	4,128	2,397	1,593	77	61
1965	4,339	2,524	1,654	88	73
1966	4,601	2,582	1,841	89	89
1967	4,780	2,694	1,889	102	95
1968	5,131	2,810	2,125	97	99
1969	5,316	2,785	2,320	105	106
1970	5,726	3,086	2,427	98	115
1971	5,788	3,057	2,494	115	122
1972	5,978	3,098	2,615	140	125
1973	6,588	3,385	2,891	172	140
1974	7,211	3,517	3,332	203	159
1975	7,871	3,948	3,517	224	182
1976	8,997	4,486	4,003	282	226
1977	9,784	4,811	4,424	304	245
1978	10,838	5,250	4,954	354	280
1979 (prelim)	12,197	5,830	5,663	400	304
1980 (est)	13,726	6,421	6,490	470	345
1981 (est)	15,290	6,950	7,455	500	385
			Constant 1972 dollars[1]		
1960	$ 4,380	$2,442	$1,785	$ 95	$ 58
1961	4,399	2,511	1,723	98	67
1962	5,175	2,913	2,082	98	82
1963	5,201	2,947	2,069	99	86
1964	5,658	3,280	2,189	105	84
1965	5,818	3,379	2,224	117	98
1966	5,989	3,359	2,398	116	116
1967	6,036	3,398	2,390	128	120
1968	6,223	3,411	2,574	118	120
1969	6,139	3,221	2,674	122	122
1970	6,271	3,383	2,654	108	126
1971	6,036	3,192	2,597	120	127
1972	5,978	3,098	2,615	140	125
1973	6,262	3,227	2,736	165	134
1974	6,333	3,112	2,900	181	140
1975	6,316	3,185	2,802	182	147
1976	6,819	3,403	3,030	214	172
1977	6,985	3,430	3,164	216	175
1978	7,226	3,501	3,302	236	187
1979 (prelim)	7,492	3,581	3,479	246	186
1980 (est)	7,749	3,629	3,659	266	195
1981 (est)	7,851	3,572	3,824	257	198

[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), and unpublished data.

See figure 2-12.

Appendix table 2-15. Development expenditures by source: 1960-81

[Dollars in millions]

Year	Total	Federal Government	Industry	Universities and colleges	Other nonprofit institutions
			Current dollars		
1960	$ 9,306	$ 6,335	$ 2,948	$ 11	$ 12
1961	9,850	6,622	3,201	11	16
1962	10,005	6,713	3,259	13	20
1963	11,352	7,768	3,548	14	22
1964	12,437	8,542	3,861	14	20
1965	13,150	8,679	4,433	15	23
1966	14,431	9,408	4,977	18	28
1967	15,310	9,500	5,761	20	29
1968	16,178	9,782	6,345	17	34
1969	16,874	9,669	7,150	17	38
1970	16,850	9,308	7,489	13	40
1971	17,235	9,397	7,781	14	43
1972	18,663	10,070	8,532	19	42
1973	20,153	10,274	9,797	33	49
1974	21,396	10,403	10,895	42	56
1975	22,723	11,011	11,598	47	67
1976	25,010	11,959	12,922	52	77
1977	27,654	13,085	14,422	58	89
1978	30,867	14,261	16,420	78	108
1979 (prelim)	34,854	15,789	18,863	80	122
1980 (est)	39,269	17,324	21,720	90	135
1981 (est)	45,003	19,793	24,965	100	145
			Constant 1972 dollars[1]		
1960	$13,526	$ 9,201	$ 4,291	$16	$18
1961	14,181	9,525	4,617	16	23
1962	14,148	9,486	4,616	18	28
1963	15,812	10,812	4,950	19	31
1964	17,070	11,717	5,306	19	28
1965	17,662	11,649	5,962	20	31
1966	18,793	12,250	6,484	23	36
1967	19,352	12,004	7,287	25	36
1968	19,609	11,860	7,687	21	41
1969	19,462	11,159	8,239	20	44
1970	18,437	10,190	8,189	14	44
1971	17,962	9,799	8,104	15	44
1972	18,663	10,070	8,532	19	42
1973	19,105	9,756	9,270	32	47
1974	18,690	9,122	9,480	38	50
1975	18,153	8,823	9,238	38	54
1976	18,940	9,062	9,781	39	58
1977	19,763	9,345	10,314	41	63
1978	20,573	9,506	10,943	52	72
1979 (prelim)	21,412	9,699	11,589	49	75
1980 (est)	22,151	9,778	12,246	51	76
1981 (est)	23,096	10,163	12,807	51	75

[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), and unpublished data.

See figure 2-12.

Appendix table 2-16. Federal funds for R & D by major budget function: 1960-81

Year	Dollars in billions				As percent of total obligation		
	Total	Defense	Space	Civilian	Defense	Space	Civilian
1960	$ 8	$ 6	(1)	$ 1	80	5	14
1961	9	7	$ 1	1	77	9	14
1962	10	7	1	2	70	14	16
1963	13	8	3	2	62	23	15
1964	14	8	4	2	55	30	15
1965	15	7	5	2	50	34	16
1966	15	8	5	3	49	33	18
1967	17	9	5	3	52	28	20
1968	16	8	4	4	52	26	22
1969	16	8	4	4	54	24	23
1970	15	8	4	4	52	23	25
1971	16	8	3	5	52	19	29
1972	17	9	3	5	54	16	30
1973	17	9	3	5	54	15	31
1974	17	9	3	6	52	14	34
1975	19	10	3	7	51	13	36
1976	21	10	3	8	50	14	36
1977	24	12	3	9	50	13	38
1978	26	13	3	11	48	12	41
1979	29	14	4	12	47	12	40
1980	32	15	4	12	47	13	40
1981	36	18	5	12	50	13	38

[1]Less than $500,000.

NOTE: Detail may not add to totals due to rounding. Estimates given for 1979 may change significantly as the result of congressional action on agency budget, requests. Data for 1971-77 are shown in obligations; data for 1978-81 are shown in budget authority.

SOURCE: Unpublished data.

See figure 2-13.

Appendix table 2-17. Federal funds[1] for R&D by budget functions: 1971-81

[Dollars in millions]

Function	Actual									Estimates	
	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Total	15,543	16,496	16,800	17,411	19,039	20,780	23,984	26,517	29,040	31,588	35,523
National defense	8,110	8,902	9,002	9,016	9,679	10,430	11,864	12,899	13,791	14,946	18,442
Space research and technology	3,048	2,932	2,824	2,702	2,764	3,130	3,365	3,481	3,969	4,587	4,929
Civilian	4,387	4,664	4,973	5,693	6,596	7,224	8,757	10,136	11,282	12,054	12,153
Health	1,288	1,547	1,585	2,069	2,170	2,351	2,629	2,968	3,401	3,694	3,825
Energy	556	574	630	759	1,363	1,649	2,562	3,134	3,461	3,603	3,515
General science	513	625	658	749	813	858	974	1,050	1,119	1,233	1,304
Natural resources and environment	416	479	554	516	624	683	753	999	1,037	999	1,037
Transportation	728	559	572	694	635	631	709	768	799	887	877
Agriculture	259	294	308	313	342	383	457	501	552	585	647
Education, training, employment, and social services	215	235	290	236	239	255	230	345	354	468	339
Community and regional development	65	66	78	82	93	109	101	92	127	119	121
International affairs	32	29	28	24	29	43	66	57	117	125	124
Veterans benefits and services	63	69	74	85	95	98	107	111	123	126	138
Commerce and housing credit	90	50	50	51	65	69	71	77	92	101	110
Income security	145	106	106	71	72	48	55	67	57	47	62
Administration of justice	10	23	33	35	44	35	30	44	47	45	28
General government	7	8	7	9	12	12	13	18	23	22	26

[1]Listed in descending order of 1981 budget authority. Data for 1971-77 are shown in obligations; data for 1978-81 are shown in budget authority.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Federal R&D Funding by Budget Function, Fiscal Years 1980-82,* June 1981, p. 3, and unpublished data.

See figure 2-14.

Appendix table 2-18. Federal expenditures for R & D plant: 1960-81

[Dollars in millions]

Year	Current dollars	Constant 1972 dollars[1]
1960	$ 443.8	$ 637.9
1961	539.1	766.2
1962	555.2	777.9
1963	673.6	928.3
1964	948.1	1,292.0
1965	1,077.4	1,436.9
1966	1,047.8	1,361.5
1967	786.1	989.6
1968	715.9	869.8
1969	652.2	756.9
1970	578.9	635.9
1971	612.7	640.8
1972	564.4	564.4
1973	638.4	611.3
1974	704.6	629.4
1975	829.7	674.2
1976	800.6	608.1
1977	800.2	569.3
1978	1,107.8	738.7
1979	1,202.8	738.6
1980 (est)	1,708.1	966.6
1981 (est)	1,791.9	921.8

[1]GNP fiscal year implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *Federal Funds for Research and Development Detailed Historical Tables: Fiscal Years 1970-1981*, November 1980, and unpublished sources.

See figure 2-15. Science Indicators—1980

Appendix table 2-19. Federal obligations for R & D plant by performer: 1962-81

[Dollars in millions]

Year	Total	Federal Government	Industry	Universities and colleges	FFRDC's[1]	Nonprofit institutions
			Current dollars			
1962	$ 555.2	NA	NA	NA	NA	NA
1963	1,168.3	NA	NA	NA	NA	NA
1964	1,098.5	NA	NA	NA	NA	NA
1965	1,131.6	$ 913.0	NA	$141.6	$ 50.2	NA
1966	858.3	629.0	NA	162.9	31.1	NA
1967	620.1	239.0	NA	111.7	138.8	NA
1968	603.8	294.2	$ 81.7	98.1	101.7	$20.9
1969	669.0	260.4	141.7	61.9	176.6	25.8
1970	524.4	166.0	102.3	56.1	169.0	28.8
1971	311.2	200.0	167.4	49.2	178.7	5.8
1972	602.1	246.6	142.4	45.3	130.4	30.0
1973	774.3	323.8	221.8	42.6	162.3	18.8
1974	766.3	308.7	294.1	25.0	118.4	8.3
1975	820.7	346.8	291.9	35.9	131.8	14.1
1976	836.7	316.8	279.6	35.2	189.6	15.6
1977	1,367.2	711.9	319.3	37.0	277.8	12.8
1978	1,295.7	518.0	334.0	54.6	376.3	12.7
1979	1,475.5	544.8	438.8	42.0	414.1	27.0
1980 (est)	2,024.7	674.1	834.0	49.0	431.6	28.5
1981 (est)	1,977.6	682.4	864.0	37.9	362.8	20.2
			Constant 1972 dollars[2]			
1962	$ 777.9	NA	NA	NA	NA	NA
1963	1,610.1	NA	NA	NA	NA	NA
1964	1,497.0	NA	NA	NA	NA	NA
1965	1,509.2	$1,217.7	NA	$188.9	$ 67.0	NA
1966	1,115.3	817.3	NA	211.7	40.4	NA
1967	780.6	300.9	NA	140.6	174.7	NA
1968	733.6	357.4	$ 99.3	119.2	123.6	$25.4
1969	776.4	302.2	164.4	71.8	204.9	29.9
1970	576.0	182.3	112.4	61.6	185.6	31.6
1971	639.2	209.2	175.1	51.5	186.9	6.1
1972	602.1	246.6	142.4	45.3	130.4	30.0
1973	741.5	310.1	212.4	40.8	155.4	18.0
1974	684.6	275.8	262.7	22.3	105.8	7.4
1975	666.9	281.8	237.2	29.2	107.1	11.5
1976	635.5	240.6	212.4	26.7	144.0	11.8
1977	972.7	506.5	227.2	26.3	197.7	9.1
1978	864.0	345.4	222.7	36.4	250.9	8.5
1979	906.1	334.6	269.5	25.8	254.3	16.6
1980 (est)	1,145.7	381.5	471.9	27.7	244.2	16.1
1981 (est)	1,017.3	351.0	444.5	19.5	186.6	10.4

[1]Federally funded research and development centers administered by universities.
[2]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NA = not available.

NOTE: Detail may not add to totals because of rounding. Totals do not include foreign performers.

SOURCE: National Science Foundation, *Federal Funds for Research, Development, and Other Scientific Activities, Fiscal Years, 1979, 1980 and 1981,* Vol. XXIX, (NSF 80-318), and unpublished data.

See figure 2-16.

Appendix table 3-1. Basic research expenditures: 1960-81

[Dollars in millions]

Year	Current dollars	Constant 1972 dollars[1]
1960	$1,197	$1,729
1961	1,401	2,004
1962	1,724	2,427
1963	1,965	2,720
1964	2,289	3,129
1965	2,555	3,416
1966	2,814	3,660
1967	3,056	3,853
1968	3,296	4,001
1969	3,441	3,985
1970	3,496	3,837
1971	3,630	3,792
1972	3,788	3,788
1973	3,924	3,745
1974	4,207	3,732
1975	4,575	3,700
1976	4,928	3,740
1977	5,485	3,906
1978	6,318	4,211
1979 (prelim)	7,164	4,400
1980 (est)	8,132	4,599
1981 (est)	8,772	4,510

[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns Science and Technology Resources, 1980* (NSF 80-308), p. 26, and unpublished data.

See figure 3-1. Science Indicators—1980

Appendix table 3-2. Basic research expenditures by source[1]: 1960-81

[Dollars in millions]

Year	Total	Federal Government	Industry	Universities and colleges[2]	Other nonprofit institutions
			Current dollars		
1960	$1,197	$ 715	$342	$ 72	$ 68
1961	1,401	874	361	85	81
1962	1,724	1,131	394	102	97
1963	1,965	1,311	425	121	108
1964	2,289	1,598	433	144	114
1965	2,555	1,809	461	164	121
1966	2,814	1,978	510	197	129
1967	3,056	2,201	492	223	140
1968	3,296	2,336	535	276	149
1969	3,441	2,441	540	298	162
1970	3,496	2,436	528	350	182
1971	3,630	2,487	547	400	196
1972	3,788	2,592	563	415	218
1973	3,924	2,687	605	408	224
1974	4,207	2,880	651	432	244
1975	4,575	3,106	705	478	286
1976	4,928	3,388	769	474	297
1977	5,485	3,778	850	519	338
1978	6,318	4,382	962	596	378
1979 (prelim)	7,164	4,937	1,112	703	412
1980 (est)	8,132	5,557	1,265	825	485
1981 (est)	8,772	5,922	1,445	885	520
			Constant 1972 dollars[3]		
1960	$1,729	$1,030	$497	$103	$ 99
1961	2,004	1,246	521	121	116
1962	2,427	1,590	558	143	136
1963	2,720	1,811	592	167	150
1964	3,129	2,182	595	196	156
1965	3,416	2,415	620	219	162
1966	3,660	2,571	665	256	168
1967	3,853	2,774	622	281	176
1968	4,001	2,837	649	335	180
1969	3,985	2,829	623	346	187
1970	3,837	2,675	578	384	200
1971	3,792	2,600	570	418	204
1972	3,788	2,592	563	415	218
1973	3,745	2,568	573	391	213
1974	3,732	2,564	567	386	215
1975	3,700	2,518	563	388	231
1976	3,740	2,573	582	360	225
1977	3,906	2,689	607	369	241
1978	4,211	2,921	641	397	252
1979 (prelim)	4,400	3,032	683	432	253
1980 (est)	4,599	3,144	714	467	274
1981 (est)	4,510	3,046	742	455	267

[1]Over 50 percent of the total basic research expenditures are accounted for by universities and colleges. Because data on individual non-Federal sources of basic research expenditures are not collected by survey but are estimated by NSF, the expenditures in the last three columns of this table are only approximations.

[2]Includes State and local government sources.

[3]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308) p. 30, and unpublished data.

See figure 3-2.

Appendix table 3-3. Basic research expenditures by performer: 1960-81

[Dollars in millions]

Year	Total	Federal Government laboratories	Industry[1]	Universities and colleges	FFRDC's[2]	Other nonprofit institutions[1]
			Current dollars			
1960	$1,197	$160	$376	$ 433	$ 97	$131
1961	1,401	206	395	536	115	149
1962	1,724	251	488	659	136	190
1963	1,965	255	522	814	159	215
1964	2,289	314	549	1,003	191	232
1965	2,555	364	592	1,138	208	253
1966	2,814	385	624	1,303	227	275
1967	3,056	435	629	1,457	250	285
1968	3,296	432	642	1,649	276	297
1969	3,441	532	618	1,711	275	305
1970	3,496	524	602	1,796	269	305
1971	3,630	544	590	1,914	260	322
1972	3,788	584	593	2,022	244	345
1973	3,924	586	631	2,053	297	357
1974	4,207	664	699	2,154	285	405
1975	4,575	701	730	2,410	309	425
1976	4,928	738	819	2,548	359	464
1977	5,485	867	911	2,795	402	510
1978	6,318	973	1,028	3,165	567	585
1979 (prelim)	7,164	1,026	1,188	3,552	718	680
1980 (est)	8,132	1,097	1,350	4,065	850	770
1981 (est)	8,772	1,172	1,550	4,300	900	850
			Constant 1972 dollars[3]			
1960	$1,729	$230	$547	$ 622	$139	$191
1961	2,004	293	570	763	163	215
1962	2,427	352	692	923	191	269
1963	2,720	351	728	1,122	219	300
1964	3,129	428	755	1,367	260	319
1965	3,416	485	796	1,518	277	340
1966	3,660	500	813	1,693	295	359
1967	3,853	548	796	1,834	315	360
1968	4,001	525	778	2,003	335	360
1969	3,985	617	712	1,985	319	352
1970	3,837	576	659	1,973	295	334
1971	3,792	569	615	2,001	272	335
1972	3,788	584	593	2,022	244	345
1973	3,745	561	597	1,966	284	337
1974	3,732	593	608	1,924	255	352
1975	3,700	570	581	1,959	251	339
1976	3,740	561	620	1,935	273	351
1977	3,906	617	651	1,988	286	364
1978	4,211	649	685	2,110	378	389
1979 (prelim)	4,400	630	730	2,181	441	418
1980 (est)	4,599	621	761	2,301	481	435
1981 (est)	4,510	630	796	2,211	463	437

[1]Includes the associated federally funded research and development centers.
[2]Federally funded research and development centers administered by universities.
[3]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308) p. 30, and unpublished data.

See figure 3-3.

Appendix table 3-4. Distribution of scientific and technical articles[1] by U. S. scientists and engineers by field and level of research: 1973 and 1979

Field[2] and level of research	1973	1979	Percent change
Clinical medicine			
Basic research	12,596	13,923	11
Applied research	19,967	20,053	([3])
Biomedicine			
Basic research	15,481	17,066	10
Applied research	640	582	−9
Biology			
Basic research	7,485	7,367	−2
Applied research	3,667	3,186	−13
Chemistry			
Basic research	9,861	8,628	−13
Applied research	705	554	−21
Physics			
Basic research	11,293	10,606	−6
Applied research	417	389	−7
Earth and space sciences			
Basic research	5,067	4,540	−10
Applied research	524	628	20
Engineering and technology			
Basic research	879	1,304	48
Applied research	11,074	7,714	−30
Mathematics			
Basic research	3,650	2,489	−32
Applied research	476	350	−26

[1]Based on about 100,000 of the articles, notes, and reviews in over 2,100 of the influential journals of the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific information.

[2]See appendix table 1-13 for the subfields included in these fields.

[3]Less than 0.5 percent.

NOTE: For this study, over 2,100 influential journals were assigned to two categories, the more basic and the more applied research. From field to field this assignment may represent somewhat different conceptions of what the basic research literature is; however, the journals retained the same categorization throughout these years. For future information, see Francis Narin, *Evaluative Bibliometrics: The Use of Publication and Citation Analysis in the Evaluation of Scientific Activity* (Cherry Hill, N.J.: Computer Horizons, Inc., 1976), pp. 198-199. See appendix table 3-5 for examples of the more basic and the more applied journals.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 3-4.

Appendix table 3-5. Examples of journals classified as "more basic" and "more applied" for purposes of the scientific and technical literature indicators in this report

Field	The more basic	The more applied
Clinical medicine	Journal of Clinical Investigation Journal of Neurophysiology	Journal of the American Medical Association New England Journal of Medicine
Biomedicine	Advances in Human Genetics Journal of Biological Chemistry	Journal of Biosocial Science Journal of Medical Genetics
Biology	Journal of Economic Entomology Journal of Experimental Zoology	Journal of the Institute of Brewing Agronomy Journal
Chemistry	Journal of the American Chemical Society Analytical Chemistry	Journal of the American Leather Chemists Association Industrial Engineering Chemistry Process Design and Development
Physics	Reviews of Modern Physics Physical Review	Photogrammetric Engineering and Remote Sensing IEEE Transactions on Sonics and Ultrasonics
Earth and space sciences	Journal of Geophysical Research Journal of the Atmospheric Sciences	Solar Energy AAPG Bulletin (American Association of Petroleum Geologists)
Engineering and technology	IEEE Transactions on Nuclear Science Journal of Chemical and Engineering Data	Journal of the Iron and Steel Institute AICHE Journal (American Institute of Chemical Engineers)
Psychology	Psychological Bulletin Journal of Experimental Psychology	Journal of Personality and Social Psychology Perceptual and Motor Skills
Mathematics	Journal of the American Statistical Association Transactions of the American Mathematical Society	Quarterly Journal of Applied Mathematics SIAM Journal on Numerical Analysis

SOURCE: Computer Horizons, Inc., unpublished.

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Appendix table 3-6. Distribution of U.S. basic research articles[1] by field and sector[2]: 1973 and 1979

Field[3]	Year	Total	Universities and colleges	Federal Gov't.	Industry	Nonprofit institutions	All other sectors[4]
		Number					
Clinical medicine	1973	12,596	8,450	1,426	896	1,257	567
	1979	13,923	9,834	1,639	689	1,298	463
Biomedicine	1973	15,481	11,869	1,471	490	1,050	601
	1979	17,066	13,277	1,622	447	1,114	556
Biology	1973	7,485	5,474	1,281	142	298	290
	1979	7,367	5,632	1,075	121	281	258
Chemistry	1973	9,861	7,046	598	1,573	185	457
	1979	8,628	6,208	514	1,311	165	430
Physics	1973	11,293	7,079	982	1,527	140	1,565
	1979	10,606	6,697	709	1,507	148	1,545
Earth and space sciences	1973	5,067	3,500	795	181	153	438
	1979	4,540	3,261	652	158	113	356
Engineering and technology	1973	879	318	91	197	16	257
	1979	1,304	456	110	259	20	459
Mathematics	1973	3,650	3,405	82	65	63	35
	1979	2,489	2,327	48	50	45	19
		Percent					
Clinical medicine	1973	100	67	11	7	10	5
	1979	100	71	12	5	9	3
Biomedicine	1973	100	77	10	3	7	3
	1979	100	78	10	3	7	3
Biology	1973	100	73	17	2	4	4
	1979	100	76	15	2	4	4
Chemistry	1973	100	71	6	16	2	5
	1979	100	72	6	15	2	5
Physics	1973	100	63	9	14	1	13
	1979	100	63	7	14	1	15
Earth and space sciences	1973	100	69	16	4	3	8
	1979	100	72	14	3	2	8
Engineering and technology	1973	100	36	10	22	2	30
	1979	100	35	8	20	2	35
Mathematics	1973	100	93	2	2	2	1
	1979	100	93	2	2	2	1

[1]Based on about 100,000 of the articles, notes and reviews per year in over 2,100 of the influential journals of the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2]When an article is written by authors from more than one sector, that article is prorated across the sectors involved. For example, if a given article has several authors from industry and the Federal Government, it is split to these sectors on the basis of the number of organizations represented and their location.

[3]See appendix table 1-13 for a description of the subfields included in these fields.

[4]Including federally funded research and development centers administered by all sectors.

NOTE: Detail may not add to totals because of rounding.

SOURCE: Computer Horizons, Inc., unpublished data.

Appendix table 3-7. Index of cooperative research[1] based on scientific and technical articles, by field, level of research, and selected research-performing sectors: 1973 and 1979

Field and level of research	Universities and colleges		Federal Government		Industry[2]		Nonprofit institutions[2]		FFRDCs[3]	
	1973	1979	1973	1979	1973	1979	1973	1979	1973	1979
Clinical medicine										
Basic research	50	54	60	61	29	41	64	68	47	49
Applied research	57	62	62	75	52	53	65	71	60	(4)
Biomedical										
Basic research	38	44	48	56	35	46	57	62	50	53
Applied research	42	54	36	(4)	(4)	(4)	50	67	(4)	(4)
Biology										
Basic research	28	35	36	46	32	49	41	45	(4)	52
Applied research	31	37	30	41	27	44	38	35	(4)	(4)
Chemistry										
Basic research	23	29	28	37	18	21	37	49	53	52
Applied research	22	33	11	5	11	7	(4)	(4)	(4)	(4)
Physics										
Basic research	37	44	28	42	24	32	42	46	50	56
Applied research	36	36	23	37	18	25	(4)	(4)	(4)	(4)
Earth and space sciences										
Basic research	37	47	44	53	49	58	49	52	47	65
Applied research	35	35	25	25	31	30	(4)	(4)	(4)	(4)
Engineering and technology										
Basic research	37	39	33	41	26	28	(4)	(4)	17	22
Applied research	32	39	28	41	19	27	24	38	35	35
Mathematics										
Basic research	23	28	26	35	39	46	49	61	(4)	(4)
Applied research	29	36	(4)	(4)	31	(4)	(4)	(4)	(4)	(4)

[1]Consisting of the percentage of all articles which were written by scientists and engineers in a given organization with S/Es from another organization; e.g., if S/E's from one university co-author an article with S/E's from another university or a corporation, it is assumed here that there was some degree of cooperative research performed.

[2]Excluding the federally funded research and development centers administered by this sector.

[3]FFRDCs administered by universities.

[4]Because the total number of articles was less than 50, index percentages have not been calculated.

NOTE: For this study, over 2,100 influential journals of the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information were assigned to two categories, the "more basic" and the "more applied" research. From field to field, this assignment may represent somewhat different conceptions of "basic research." However, within each field the same concept applies for both 1973 and 1979 because the category into which each 1973 journal was placed is constant over the entire period. When an article is written by researchers from more than one sector, the article is counted in each such sector and not prorated as in the other indicators of S&T literature. For futher information, see Francis Narin, *Evaluative Bibliometrics: The Use of Publication and Citation Analysis in the Evaluation of Scientific Activity* (Cherry Hill, N.J.: Computer Horizons, Inc., 1976), pp. 198-199.

SOURCE: Computer Horizons, Inc., unpublished data.

See table 3-1 in text.

Appendix table 3-8. Federal obligations for basic research by agency: 1963-81

[Dollars in millions]

Year	All agencies	USDA	DOD	HHS[1]	DOE[2]	NASA	NSF	All other agencies
	Current dollars							
1963	$1,152	$ 56	$231	$236	$219	$210	$141	$ 59
1964	NA	68	241	274	238	NA	155	67
1965	NA	90	263	303	258	NA	171	76
1966	NA	94	262	326	281	NA	223	94
1967	1,846	100	284	490	302	328	239	103
1968	1,841	100	263	517	282	321	252	106
1969	1,945	107	276	537	285	380	248	112
1970	1,877	116	247	513	287	358	245	111
1971	1,946	118	262	575	277	327	273	114
1972	2,165	137	270	665	268	332	368	124
1973	2,193	143	258	667	275	350	392	107
1974	2,339	146	244	850	270	306	415	109
1975	2,536	154	236	904	313	309	486	134
1976	2,700	171	248	986	346	293	524	132
1977	3,191	204	295	1,119	389	414	625	145
1978	3,619	243	319	1,292	441	480	678	167
1979	4,097	256	363	1,576	463	513	733	193
1980 (est.)	4,682	275	539	1,758	523	559	819	209
1981 (est.)	5,038	319	612	1,871	594	541	877	224
	Constant 1972 dollars[3]							
1963	$1,589	$ 77	$319	$326	$302	$290	$195	$ 81
1964	NA	92	328	373	324	NA	211	91
1965	NA	120	351	404	344	NA	228	101
1966	NA	122	340	424	365	NA	290	122
1967	2,325	126	358	617	380	413	301	130
1968	2,237	122	320	628	343	390	306	129
1969	2,257	124	320	623	331	441	288	130
1970	2,076	128	272	564	316	394	269	122
1971	2,036	123	274	602	290	342	286	119
1972	2,165	137	270	665	268	332	368	124
1973	2,101	137	247	639	263	335	376	103
1974	2,079	130	217	756	240	272	369	97
1975	2,036	124	189	726	251	248	390	108
1976	2,027	128	186	740	260	220	393	99
1977	2,241	143	207	786	273	291	439	102
1978	2,380	160	210	850	290	316	446	110
1979	2,480	155	220	954	280	311	444	117
1980 (est.)	2,649	156	305	995	296	316	463	118
1981 (est.)	2,592	164	315	962	306	278	451	115

[1]Data for 1963-78 represent obligations by the Department of Health, Education and Welfare; 1979-81 data represent obligations by the Department of Health and Human Services.

[2]Data for 1963-73 represent obligations by the Atomic Energy Commission; 1974-76 represent obligations by the Energy Research and Development Administration; 1977-79 represent obligations by the Department of Energy.

[3]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: Details may not add to totals because of rounding. Data for DOD beginning in 1980 reflects a change in the basis on which DOD classifies basic research programs. Revised prior year data are not yet available.

NA = Not available.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Fiscal Years 1979, 1980, and 1981*, Vol. XXIX (NSF 80-318), and unpublished data.

See figure 3-5.

Appendix table 3-9. Federal obligations for basic research as a percent of each agency's R&D obligations by agency: 1963-81

Year	All agencies	USDA	DOD	HHS	DOE[1]	NASA	NSF	All other agencies
	Basic research as a percent of all R&D obligations							
1963	9	33	3	36	20	7	92	20
1964	NA	36	3	35	19	NA	91	22
1965	NA	40	4	35	21	NA	91	22
1966	NA	40	4	32	23	NA	91	17
1967	11	40	4	43	24	7	91	15
1968	12	39	3	41	21	7	89	17
1969	12	41	4	41	20	10	91	15
1970	12	41	3	42	21	9	85	11
1971	13	39	3	39	21	10	81	8
1972	13	39	3	38	21	11	81	11
1973	13	39	3	36	20	11	82	8
1974	13	39	3	37	18	10	75	9
1975	13	37	3	38	15	10	82	9
1976	13	37	3	38	14	9	86	9
1977	13	37	3	40	11	11	90	9
1978	14	39	3	40	10	12	91	8
1979	14	39	3	45	10	12	91	8
1980 (est.)	14	39	3	45	11	11	91	8
1981 (est.)	14	42	3	46	12	10	91	9
	Federal obligations for basic research (Current dollars in millions)							
1963	$1,152	$ 56	$231	$236	$219	$210	$141	$ 59
1964	NA	68	241	274	238	NA	155	67
1965	NA	90	263	303	258	NA	171	76
1966	NA	94	262	326	281	NA	223	94
1967	1,846	100	284	490	302	328	239	103
1968	1,841	100	263	517	282	321	252	106
1969	1,945	107	276	537	285	380	248	112
1970	1,877	116	247	513	287	358	245	111
1971	1,946	118	262	575	277	327	273	114
1972	2,165	137	270	665	268	332	368	124
1973	2,193	143	258	667	275	350	392	107
1974	2,339	146	244	850	270	306	415	109
1975	2,536	154	236	904	313	309	486	134
1976	2,700	171	248	986	346	293	524	132
1977	3,191	204	295	1,119	389	414	625	145
1978	3,619	243	319	1,292	441	480	678	167
1979	4,097	256	363	1,576	463	513	733	193
1980 (est.)	4,509	288	430	1,699	520	538	821	213
1981 (est.)	4,902	324	515	1,788	582	545	906	242

(continued)

Table 3-9. (Continued)

	Federal obligations for all R & D (Current dollars in millions)							
1963	$12,495	$168	$ 7,286	$ 656	$1,078	$2,857	$154	$ 295
1964	14,225	189	7,262	777	1,236	4,287	170	304
1965	14,614	225	6,797	869	1,241	4,952	187	343
1966	15,320	235	7,024	1,014	1,212	5,050	244	541
1967	16,529	253	8,049	1,147	1,257	4,867	262	694
1968	15,921	254	7,709	1,252	1,369	4,429	284	625
1969	15,641	260	7,696	1,297	1,406	3,963	274	744
1970	15,340	281	7,360	1,221	1,346	3,800	289	1,043
1971	15,543	305	7,509	1,476	1,303	3,258	337	1,355
1972	16,496	350	8,318	1,751	1,298	3,157	455	1,167
1973	16,800	366	8,404	1,838	1,363	3,061	480	1,288
1974	17,411	379	8,420	2,290	1,489	3,002	556	1,274
1975	19,039	420	9,012	2,398	2,047	3,064	595	1,503
1976	20,780	462	9,655	2,584	2,464	3,447	609	1,559
1977	23,984	547	10,963	2,823	3,536	3,703	697	1,715
1978	26,388	621	11,554	3,207	4,245	3,876	749	2,136
1979	28,978	663	12,506	3,505	4,639	4,411	808	2,446
1980 (est.)	31,878	732	13,788	3,777	4,950	5,114	904	2,613
1981 (est.)	35,492	778	16,604	3,908	4,995	5,398	995	2,814

[1] Data for years 1963-73 are from Atomic Energy Commission; 1974-76 are from Energy Research and Development Administration; 1977-79 are from Department of Energy.

NOTE: Details may not add to totals because of rounding. Data for R & D beginning in 1980 reflects a change in the basis on which R & D classifies basic research programs. Revised prior year data is not yet available.

NA = Not available.

SOURCES: National Science Foundation, *Federal Funds for Research, Development, and Other Scientific Activities, Fiscal Years, 1979, 1980, and 1981,* Vol. XXIX (NSF 80-318); *Detailed Historical Tables: Fiscal Years 1970-1981,* November 1980, and earlier volumes, and unpublished data.

See figure 3-7.

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Appendix table 3-10. Federal obligations for basic research by field of science: 1963-81

[Dollars in millions]

Field[1]	1963	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980 (est.)	1981 (est.)
All fields	$1,152	$1,846	$1,841	$1,945	$1,877	$1,946	$2,165	$2,193	$2,339	$2,536	$2,700	$3,191	$3,619	$4,097	$4,509	$4,902
Life sciences	372	706	716	717	692	745	870	875	1,022	1,104	1,206	1,372	1,572	1,871	2,035	2,176
Biological & agricultural	200	NA	NA	NA	486	522	604	607	685	744	818	929	1,077	1,277	1,399	1,499
Medical[1]	172	NA	NA	NA	193	205	241	241	314	333	359	408	453	540	585	624
Other life sciences	([2])	NA	NA	NA	13	17	25	27	23	27	29	35	42	52	52	53
Environmental sciences[3]	164	209	199	235	246	271	279	284	298	288	300	395	454	463	509	530
Physical sciences	404	596	589	651	578	576	618	612	633	692	710	865	917	1,022	1,123	1,227
Chemistry	84	NA	NA	NA	123	106	138	144	147	156	162	207	200	221	249	276
Physics	228	NA	NA	NA	321	340	349	339	348	366	384	449	499	512	579	632
Astronomy	74	NA	NA	NA	129	122	125	119	132	161	159	193	210	280	285	303
Other physical sciences	20	NA	NA	NA	5	8	5	10	7	8	5	16	9	9	10	15
Psychology	35	53	47	47	48	45	52	46	48	59	43	54	80	71	78	86
Mathematics and computer sciences	40	64	66	54	56	51	63	57	48	58	69	79	91	96	108	130
Engineering	110	153	153	152	182	171	187	206	192	237	243	306	344	395	443	521
Social sciences	25	55	60	72	64	70	80	79	73	74	86	95	124	130	142	155
Other sciences	2	10	11	17	11	16	16	36	26	26	43	26	35	50	70	78

[1]See appendix table 3-11 for definitions of what is included in each of the fields presented above.
[2]Less than $0.5 million.
[3]Includes atmospheric sciences, geological sciences, oceanography and other environmental sciences (see also appendix table 3-11).

NA = not available.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Fiscal Years 1979, 1980, and 1981*, Vol. XXIX (NSF 80-318), p. 63, and earlier volumes.

See figures 3-6 and 3-8.

Appendix table 3-11. Fields and subfields of Federal obligations for basic research shown in figures 3-6 and 3-8 and appendix table 3-10

Field of science	Illustrative subfields
Biological (excluding environmental)	anatomy; biochemistry; biology; biometry and biostatistics; biophysics; botany; cell biology; entomology and parasitology; genetics; microbiology; neuroscience (biological); nutrition; physicology; zoology
Environmental biology	ecosystem sciences; evolutionary biology; limnology; physiological ecology; population biology; population and biotic community ecology; systematics
Agricultural	agronomy; animal sciences; food science and technology; fish and wildlife; forestry; horticulture; plant sciences; soils and soil science; phytopathology; phytoproduction; agriculture, general
Medical	internal medicine; neurology; obstetrics and gynecology; ophthalmology; otolaryngology; pediatrics; preventive medicine; pathology; pharmacology; psychiatry; radiology; surgery; dentistry; pharmacy; veterinary medicine
Other life sciences	multidisciplinary and interdisciplinary projects that cannot be classifed in the broader life sciences fields
Atmospheric sciences	aeronomy; solar; weather modification; extraterrestrial atmospheres; meteorology
Geological sciences	engineering geophysics; general geology; geodesy and gravity; geomagnetism; hydrology; inorganic geochemistry; isotopic geochemistry; organic geochemistry; laboratory geophysics; paleomagnetism; paleontology; physical geography and cartography; seismology; soil sciences
Oceanography	biological oceanography; chemical oceanography; physical oceanography; marine geophysics
Other environmental sciences	multidisciplinary and interdisciplinary projects that cannot be classified in the broader environmental sciences fields
Mathematics	algebra; analysis; applied mathematics; foundations and logic; geometry; numerical analysis; statistics; topology
Computer sciences	programming languages; computer and information sciences (general); design, development, and application of computer capabilities to data storage and manipulation; information sciences and systems; systems analysis
Other mathematics and computer sciences	multidisciplinary and interdisciplinary projects that cannot be classified in the broader fields of mathematics and computer sciences.
Engineering:	
Aeronautical	aerodynamics
Astronautical	aerospace; space technology
Chemical	petroleum; petroleum refining; process
Civil	architectural; hydraulic; hydrologic; marine; sanitary and environmental; structural; transportation
Electrical	communication; electronic; power
Mechanical	engineering mechanics
Metallurgy and materials	ceramic; mining; textile; welding
Other engineering	agricultural; industrial and management; nuclear; ocean engineering; systems; multidisciplinary and interdisciplinary projects that cannot be classified in the broader fields of engineering.

(continued)

Table 3-11. (Continued)

Anthropology	archaeology; cultural and personality; social and ethnology; applied anthropology
Economics	econometrics and economic statistics; history of economic thought; international economics; industrial, labor and agricultural economics; macroeconomics; microeconomics; public finance and fiscal policy; theory; economics systems and development
Political science	area or regional studies; comparative government; history of political ideas; international relations and law; national political and legal systems; political theory; public administration
Sociology	comparative and historical; complex organizations; culture and social structure; demography; group interactions; social problems and social welfare; sociological theory
Other social sciences	linguistics; research in education; research in history; socioeconomic geography; research in law, e.g., attempts to assess impact on society in legal systems and practices
Psychology: Biological aspects	experimental psychology; animal behavior; clinical psychology; comparative psychology; ethology
Social aspects	social psychology; educational, personnel, vocational psychology, and testing; industrial and engineering psychology; development and personality
Other psychological sciences	multidisciplinary and interdisciplinary projects that cannot be classified in the broader fields of psychology.
Astronomy	laboratory astrophysics; optical astronomy; radio astronomy; theoretical astrophysics; X-ray, Gamma-ray, neutrino astronomy
Chemistry	inorganic; organo-metallic; organic; physical
Physics	acoustics; atomic and molecular; condensed matter; elementary particle; nuclear structure; optics; plasma
Other physical sciences	multidisciplinary and interdisciplinary projects that cannot be classified in the broader fields of physical sciences.
Other sciences	multidisciplinary and interdisciplinary projects that cannot be classified within one of the broad fields of science above.

SOURCE: National Science Foundation, *Annual Survey of Federal Funds for Research and Development, and Other Scientific Activities, Fiscal Years 1980, 1981 and 1982,* Vol. XXX (NSF Form 818), pp. 6-8.

Appendix table 4-1. Expenditures for industrial R & D by source of funds: 1960-81

[Dollars in millions]

Year	Current dollars			Constant 1972 dollars[1]		
	Total	Company[2]	Federal Government	Total	Company[2]	Federal Government
1960	$10,509	$ 4,428	$ 6,081	$15,297	$ 6,445	$ 8,852
1961	10,908	4,668	6,240	15,733	6,733	9,000
1962	11,464	5,029	6,435	16,237	7,122	9,113
1963	12,630	5,360	7,270	17,622	7,479	10,144
1964	13,512	5,792	7,720	18,569	7,959	10,609
1965	14,185	6,445	7,740	19,077	8,667	10,409
1966	15,548	7,216	8,332	20,256	9,401	10,855
1967	16,385	8,020	8,365	20,725	10,144	10,581
1968	17,429	8,869	8,560	21,116	10,745	10,371
1969	18,308	9,857	8,451	21,094	11,357	9,737
1970	18,067	10,288	7,779	19,756	11,250	8,506
1971	18,320	10,654	7,666	19,081	11,097	7,985
1972	19,552	11,535	8,017	19,552	11,535	8,017
1973	21,249	13,104	8,145	20,106	12,399	7,706
1974	22,887	14,667	8,220	19,915	12,762	7,153
1975	24,187	15,582	8,605	19,263	12,410	6,853
1976	26,997	17,436	9,561	20,435	13,198	7,237
1977	29,928	19,407	10,521	21,403	13,878	7,524
1978 (prelim.)	33,164	22,001	11,163	22,103	14,662	7,440
1979 (prelim.)	37,606	25,264	12,342	23,104	15,521	7,582
1980 (est.)	42,750	29,050	13,700	24,103	16,379	7,724
1981 (est.)	49,150	33,400	15,750	25,216	17,135	8,080

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
[2] Includes all sources other than the Federal Government.

NOTE: Detail may not add to totals because of rounding.

SOURCES: 1960-71: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), p. 25; 1978-81: National Science Foundation, preliminary data.

See figure 4-1.

Science Indicators—1980

Appendix table 4-2. R & D scientists and engineers[1] employed in industry: 1960-80

[In thousands]

Year	Number
1960	292.0
1961	312.1
1962	312.0
1963	327.3
1964	340.2
1965	343.6
1966	353.2
1967	367.2
1968	376.7
1969	387.1
1970	384.2
1971	367.0
1972	350.2
1973	357.7
1974	360.0
1975	363.3
1976	364.4
1977	382.8
1978	403.7
1979 (prelim.)	421.0
1980 (prelim.)	444.5

[1]Full-time equivalent, as of January of each year.

SOURCES: National Science Foundation, *Research and Development in Industry, 1978. Detailed Statistical Tables* (NSF 80-307), p. 31; National Science Foundation, *Research and Development in Industry, 1971* (NSF 73-305), p. 47; and National Science Foundation, preliminary data.

See figure 4-2. Science Indicators — 1980

Appendix table 4-3. Industrial R & D expenditures for basic research, applied research, and development: 1960-81

[Dollars in millions]

Year	Total	Basic research	Applied research	Development
	Current dollars			
1960	$10,509	$376	$2,029	$ 8,104
1961	10,908	395	1,977	8,536
1962	11,464	488	2,449	8,527
1963	12,630	522	2,457	9,651
1964	13,512	549	2,600	10,363
1965	14,185	592	2,658	10,935
1966	15,548	624	2,843	12,081
1967	16,385	629	2,915	12,841
1968	17,429	642	3,124	13,663
1969	18,308	618	3,287	14,403
1970	18,067	602	3,427	14,038
1971	18,320	590	3,415	14,315
1972	19,552	593	3,514	15,445
1973	21,249	631	3,825	16,793
1974	22,887	699	4,288	17,900
1975	24,187	730	4,570	18,887
1976	26,997	819	5,112	21,066
1977	29,928	911	5,656	23,361
1978 (prelim.)	33,164	1,028	6,268	25,868
1979 (prelim.)	37,606	1,188	7,114	29,304
1980 (est.)	42,750	1,350	8,150	33,250
1981 (est.)	49,150	1,550	9,350	38,250
	Constant 1972 dollars[1]			
1960	$15,297	$547	$2,954	$11,796
1961	15,733	570	2,851	12,312
1962	16,237	692	3,469	12,076
1963	17,622	728	3,428	13,466
1964	18,569	755	3,573	14,241
1965	19,077	796	3,575	14,706
1966	20,256	813	3,704	15,739
1967	20,725	796	3,687	16,242
1968	21,116	778	3,785	16,553
1969	21,094	712	3,787	16,595
1970	19,756	659	3,747	15,350
1971	19,081	615	3,556	14,910
1972	19,552	593	3,514	15,445
1973	20,106	597	3,620	15,889
1974	19,915	608	3,731	15,576
1975	19,263	581	3,640	15,042
1976	20,435	620	3,869	15,946
1977	21,403	651	4,045	16,707
1978 (prelim.)	22,103	685	4,178	17,240
1979 (prelim.)	23,104	730	4,371	18,003
1980 (est.)	24,103	761	4,595	18,747
1981 (est.)	25,216	796	4,797	19,623

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCES: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), pp. 26-28; and National Science Foundation, preliminary data.

See figure 4-3.

Appendix table 4-4. Doctoral scientists and engineers employed in industrial R & D[1], by primary work activity: 1973-79

Activity	1973	1975	1977	1979
	Number			
All scientists and engineers	53,400	64,600	71,500	82,800
Primarily in R & D	38,000	44,500	47,300	54,600[2]
R & D performance	23,800	28,700	31,300	30,800
Basic research	3,500	4,300	4,600	4,700
Applied research	13,200	15,100	16,500	14,300
Design and development	7,000	9,400	10,200	11,800
Management of R & D	14,200	15,700	15,900	23,800[2]
Primarily not in R & D	15,400	20,200	24,200	28,300[2]
	Percent of all industrial S/E's			
All scientists and engineers	100	100	100	100
Primarily in R & D	71	69	66	66[2]
R & D performance	44	44	44	37
Basic research	7	7	6	6
Applied research	25	23	23	17
Design and development	13	15	14	14
Management of R & D	27	24	22	29[2]
Primarily not in R & D	29	31	34	34[2]

[1] R & D includes design.
[2] 1979 data may reflect the change in the classification of managers that was made in that year.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States: 1979* (NSF 80-323), p. 5.

See figure 4-4.

Science Indicators—1980

Appendix table 4-5. R&D expenditures, by industry: 1960-79

[Dollars in millions]

Industry	1960	1962	1964	1966	1968	1970	1972	1974	1975	1976	1977	1978 (prelim.)	1979 (prelim.)
	Current dollars in millions												
Total	$10,509	$11,464	$13,512	$15,548	$17,429	$18,067	$19,552	$22,887	$24,187	$26,997	$29,928	$33,164	$37,606
Food and kindred products	104	121	144	164	184	230	259	298	335	355	395	429	475
Textiles and apparel	38	28	32	51	58	58	61	69	70	82	81	84	92
Lumber, wood products, and furniture	10	10	12	12	20	52	64	84	88	107	127	133	148
Paper and allied products	56	65	77	117	144	178	189	237	249	313	336	391	454
Chemicals and allied products	980	1,175	1,284	1,407	1,589	1,773	1,932	2,450	2,727	3,017	3,256	3,534	4,010
Industrial chemicals	666	738	865	918	981	1,031	1,031	1,299	1,391	1,524	1,685	1,820	2,018
Drugs and medicines	162	195	234	308	398	485	607	807	981	1,091	1,154	1,270	1,431
Other chemicals	152	242	185	181	210	257	294	344	354	401	417	444	561
Petroleum refining and extraction	296	310	393	371	437	515	468	622	693	767	918	1,060	1,224
Rubber products	121	141	158	168	223	276	377	469	467	502	491	488	551
Stone, clay, and glass products	88	96	109	117	142	167	183	217	233	263	287	321	348
Primary metals	177	171	195	232	251	275	277	358	443	506	534	549	613
Ferrous metals and products[4]	102	97	116	139	135	149	146	181	215	256	261	266	293
Nonferrous metals and products	75	74	79	93	115	126	130	177	228	250	273	283	320
Fabricated metal products	145	146	148	154	183	207	253	313	324	358	394	396	445
Nonelectrical machinery	949	914	1,015	1,217	1,483	1,729	2,158	2,985	3,196	3,487	3,967	4,579	5,142
Office, computing, and accounting machines	[1]	[1]	[1]	[1]	[1]	[1]	1,456	2,103	2,220	2,402	2,766	3,235	3,597
Electrical equipment	2,532	2,639	2,972	3,626	4,083	4,220	4,680	5,011	5,105	5,636	5,937	6,591	7,584
Radio and TV receiving equipment	[2]	[2]	[2]	47	55	70	48	51	50	52	61	51	60
Electronic components	[1]	[1]	[1]	[1]	[1]	[1]	330	489	549	691	748	824	1,006
Communication equipment and communication	1,324	1,591	1,872	2,249	2,520	2,604	2,583	2,424	2,385	2,511	2,809	3,189	3,767
Other electrical equipment	1,208	1,048	1,100	1,330	1,508	1,546	1,719	2,047	2,121	2,382	2,318	2,527	2,751
Motor vehicles and other transportation equipment	884	999	1,182	1,344	1,499	1,591	2,010	2,476	2,430	2,872	3,444	3,849	4,472
Motor vehicles and motor vehicle equipment	[1]	[1]	[1]	[1]	[1]	[1]	1,954	2,389	2,340	2,778	3,325	3,718	4,320
Other transportation equipment	[1]	[1]	[1]	[1]	[1]	[1]	56	87	90	94	119	131	152
Aircraft and missiles	3,514	4,042	5,078	5,526	5,765	5,219	4,950	5,278	5,713	6,339	7,104	7,680	8,414
Professional and scientific instruments	329	309	331	468	663	744	838	1,075	1,173	1,331	1,487	1,713	2,024
Scientific and mechanical measuring instruments	160	101	74	87	118	131	163	221	266	325	390	476	592
Optical, surgical, photographic, and other instruments	169	208	257	381	545	613	675	854	907	1,007	1,097	1,237	1,432
Other manufacturing industries	119	65	65	77	101	128	146	177	205	217	250	273	293
Nonmanufacturing industries	168	234	319	497	603	705	707	768	735	845	921	1,094	1,317

(continued)

Table 4-5. (Continued)

Industry	1960	1962	1964	1966	1968	1970	1972	1974	1975	1976	1977	1978 (prelim.)	1979 (prelim.)
	Constant 1972 dollars[3]												
Total	$15,297	$16,236	$18,568	$20,255	$21,116	$19,756	$19,552	$19,916	$19,263	$20,435	$21,403	$22,102	$23,104
Food and kindred products	151	171	198	214	223	252	259	259	267	269	282	286	292
Textiles and apparel	55	40	44	66	70	63	61	60	56	62	58	56	57
Lumber, wood products, and furniture	15	14	16	16	24	57	64	73	70	81	91	89	91
Paper and allied products	82	92	106	152	174	195	189	206	198	237	240	261	279
Chemicals and allied products	1,426	1,664	1,764	1,833	1,925	1,939	1,932	2,132	2,172	2,284	2,329	2,355	2,464
Industrial chemicals	969	1,045	1,189	1,196	1,189	1,127	1,031	1,130	1,108	1,154	1,205	1,213	1,240
Drugs and medicines	236	276	322	401	482	530	607	702	781	826	825	846	879
Other chemicals	221	343	254	236	254	281	294	299	282	304	298	296	345
Petroleum refining and extraction	431	439	540	483	529	563	468	541	553	581	657	706	752
Rubber products	176	200	217	219	270	302	377	408	372	380	351	325	339
Stone, clay, and glass products	128	136	150	152	172	183	183	189	186	199	205	214	214
Primary metals	258	242	268	302	304	301	277	311	353	383	382	366	377
Ferrous metals and products[4]	149	137	159	181	164	163	146	158	171	194	187	177	180
Nonferrous metals and products	109	105	109	121	139	138	130	154	182	189	195	189	197
Fabricated metal products	211	207	203	201	222	226	253	272	258	271	282	264	273
Nonelectrical machinery	1,381	1,294	1,395	1,585	1,797	1,891	2,158	2,597	2,545	2,639	2,837	3,052	3,159
Office, computing, and accounting machines	([1])	([1])	([1])	([1])	([1])	([1])	1,456	1,830	1,768	1,818	1,978	2,156	2,210
Electrical equipment	3,686	3,737	4,084	4,724	4,947	4,615	4,680	4,360	4,066	4,266	4,246	4,393	4,659
Radio and TV receiving equipment	([2])	([2])	([2])	61	67	77	48	44	40	39	44	34	37
Electronic components	([1])	([1])	([1])	([1])	([1])	([1])	330	426	437	523	535	549	618
Communication equipment	1,927	2,253	2,572	2,930	3,053	2,847	2,583	2,109	1,899	1,901	2,009	2,125	2,314
Other electrical equipment	1,758	1,484	1,512	1,733	1,827	1,691	1,719	1,781	1,689	1,803	1,658	1,684	1,690
Motor vehicles and other transportation equipment	1,287	1,415	1,624	1,751	1,816	1,740	2,010	2,155	1,935	2,174	2,463	2,565	2,747
Motor vehicles and motor vehicle equipment	([1])	([1])	([1])	([1])	([1])	([1])	1,954	2,079	1,864	2,103	2,378	2,478	2,654
Other transportation equipment	([1])	([1])	([1])	([1])	([1])	([1])	56	76	72	71	85	87	93
Aircraft and missiles	5,115	5,724	6,978	7,199	6,984	5,707	4,950	4,593	4,550	4,798	5,080	5,118	5,169
Professional and scientific instruments	479	438	455	610	803	814	838	935	934	1,007	1,063	1,142	1,243
Scientific and mechanical measuring instruments	233	143	102	113	141	143	163	192	212	246	279	317	364
Optical, surgical, photographic, and other instruments	246	295	353	496	660	670	675	743	722	762	785	824	880
Other manufacturing industries	173	92	89	100	122	140	146	154	163	164	179	182	180
Nonmanufacturing industries	245	331	439	647	731	771	707	668	585	640	659	729	809

[1]Data not tabulated at this level of detail prior to 1972.
[2]Included in the other electrical equipment group.
[3]GNP implicit deflators used to convert current dollars to constant 1972 dollars.
[4]Part of these expenditures was included in the nonferrous metals and products group in 1960-64.

NOTE: Detail may not add to totals because of rounding.

SOURCES: 1960-1966: National Science Foundation, *Research and Development in Industry, 1971* (NSF 73-305), p. 28; 1968: National Science Foundation, unpublished data; 1970-1977: National Science Foundation, *Research and Development in Industry, 1978* (NSF 80-307), p. 11; 1978, 1979: National Science Foundation, preliminary data.

See figure 4-5.

Appendix table 4-6. Company and Federal funding of industrial R & D for selected industries: 1969 and 1979

[Dollars in millions]

Industry	Total 1969	Total 1979 (prelim.)	Federal 1969	Federal 1979 (prelim.)	Company[1] 1969	Company[1] 1979 (prelim.)
	Current dollars					
Total	$18,308	$37,606	$ 8,451	$12,342	$ 9,857	$25,264
Chemicals and allied products	1,660	4,010	192	379	1,468	3,631
Industrial chemicals	1,007	2,018	165	360	842	1,658
Drugs and medicines and other chemicals	653	1,992	27	19	626	1,973
Petroleum refining and extraction	467	1,224	10	142	457	1,082
Primary metals	257	613	10	33	247	580
Ferrous metals and products	136	293	2	5	135	288
Nonferrous metals and products	121	320	9	28	112	292
Fabricated metal products	182	445	8	36	174	409
Nonelectrical machinery	1,546	5,142	260	673	1,286	4,469
Electrical equipment	4,347	7,584	2,390	3,224	1,957	4,363
Aircraft and missiles	5,878	8,414	4,524	6,132	1,354	2,281
Professional and scientific instruments	742	2,024	237	223	505	1,801
Scientific and mechanical measuring instruments	123	592	32	35	91	557
Optical, surgical, photographic, and other instruments	619	1,432	205	188	414	1,244
All other manufacturing industries	2,574	6,833	372	855	2,202	5,976
Nonmanufacturing industries	655	1,317	448	645	207	672
	Constant 1972 dollars[2]					
Total	$21,095	$23,104	$ 9,737	$ 7,582	$11,357	$15,521
Chemicals and allied products	1,913	2,464	221	233	1,691	2,231
Industrial chemicals	1,160	1,240	190	221	970	1,019
Drugs and medicines and other chemicals	752	1,224	31	12	721	1,212
Petroleum refining and extraction	538	752	12	87	527	665
Primary metals	296	377	12	20	285	356
Ferrous metals and products	157	180	2	3	156	177
Nonferrous metals and products	139	197	10	17	129	179
Fabricated metal products	210	273	9	22	200	251
Nonelectrical machinery	1,781	3,159	300	413	1,482	2,746
Electrical equipment	5,009	4,659	2,754	1,981	2,255	2,680
Aircraft and missiles	6,773	5,169	5,213	3,767	1,560	1,401
Professional and scientific instruments	855	1,243	273	137	582	1,106
Scientific and mechanical measuring instruments	142	364	37	22	105	342
Optical, surgical, photographic, and other instruments	713	880	236	116	477	764
All other manufacturing industries	2,966	4,198	429	525	2,537	3,671
Nonmanufacturing industries	755	809	516	396	239	413

[1]Includes all sources other than the Federal Government.
[2]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCES: National Science Foundation, *Research and Development in Industry, 1977* (NSF 79-313), pp. 13, 16, 19; and National Science Foundation, preliminary data.

See table 4-2 in text

Appendix table 4-7. Domestic R & D funding by U. S. corporations and foreign funding by U. S. corporations and their foreign affiliates: 1974-79

[Dollars in millions]

	1974				1975				1976			
	Domestic	Foreign[1]	Total[1]	Foreign as percent of domestic	Domestic	Foreign	Total	Foreign as percent of domestic	Domestic	Foreign	Total	Foreign as percent of domestic
Total	$14,667	$1,290	$15,957	8.8	$15,582	$1,441	$17,023	9.2	$17,436	$1,644	$19,080	9.4
Food and kindred products	297	27	324	9.1	NA	23	NA	NA	NA	29	NA	NA
Paper and allied products	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chemicals and allied products	2,236	208	2,444	9.3	2,490	269	2,759	10.8	2,751	312	3,063	11.3
Petroleum refining and extraction	603	NA	NA	NA	NA	NA	NA	NA	715	NA	NA	NA
Stone, clay, and glass products	203	7	210	3.4	NA	7	NA	NA	NA	NA	NA	NA
Primary metals	350	3	353	.9	422	9	431	2.1	481	12	493	2.5
Fabricated metal products	299	NA	NA	NA	297	NA	NA	NA	322	22	344	6.8
Nonelectrical machinery	2,473	258	2,731	10.4	2,687	331	3,018	12.3	2,955	352	3,307	11.9
Electrical equipment	2,704	228	2,932	8.4	2,798	232	3,030	8.3	3,081	263	3,344	8.5
Electronic components	306	4	310	1.3	NA	7	NA	NA	NA	9	NA	NA
Motor vehicles and other transportation equipment	2,141	364	2,505	17.0	2,065	373	2,438	18.1	2,395	423	2,818	17.7
Aircraft and missiles	1,278	42	1,320	3.3	1,285	39	1,324	3.0	1,418	41	1,459	2.9
Professional and scientific instruments	908	39	947	4.3	1,001	49	1,050	4.9	1,168	49	1,217	4.2
Nonmanufacturing industries	305	3	308	1.0	425	4	429	.9	471	4	475	.8

(continued)

Table 4-7. (Continued)

	1977				1978 (prelim.)				1979 (prelim.)			
	Domestic	Foreign	Total	Foreign as percent of domestic	Domestic	Foreign	Total	Foreign as percent of domestic	Domestic	Foreign	Total	Foreign as percent of domestic
Total	$19,407	$1,858	$21,265	9.6	$22,001	$2,195	$ 4,396	10.0	$25,264	$2,709	$27,973	10.7
Food and kindred products	NA	32	NA	NA	NA	43	NA	NA	NA	52	NA	NA
Paper and allied products	NA	NA	NA	NA	NA	33	NA	NA	NA	26	NA	NA
Chemicals and allied products	2,956	332	3,288	11.2	3,167	399	3,566	12.6	3,631	450	4,081	12.4
Petroleum refining and extraction	842	NA	NA	NA	939	87	1,026	9.3	1,082	91	1,173	8.4
Stone, clay, and glass products	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Primary metals	507	10	517	2.0	521	11	532	2.1	580	14	594	2.4
Fabricated metal products	349	24	373	6.9	359	26	385	7.2	409	35	444	8.6
Nonelectrical machinery	3,391	415	3,806	12.2	3,987	469	4,456	11.8	4,469	542	5,011	12.1
Electrical equipment	3,238	287	3,525	8.9	3,727	364	4,091	9.8	4,363	475	4,838	10.9
Electronic components	NA	13	NA	NA	NA	17	NA	NA	NA	24	NA	NA
Motor vehicles and other transportation equipment	2,887	508	3,395	17.6	3,268	NA	NA	NA	3,692	NA	NA	NA
Aircraft and missiles	1,563	44	1,607	2.8	1,864	51	1,915	2.7	2,281	127	2,368	5.6
Professional and scientific instruments	1,313	53	1,366	4.0	1,530	65	1,595	4.2	1,801	87	1,888	4.8
Nonmanufacturing industries	506	9	515	1.8	574	3	577	.5	672	4	676	.6

[1]Based on data obtained from the top 200 U.S. R&D-performing companies.

NA = Not available.

SOURCES: National Science Foundation, *Research and Development in Industry, 1978, Detailed Statistical Tables* (NSF 80-307), pp. 14, 16; and National Science Foundation, preliminary data.

See table 4-3 in text.

Appendix table 4-8. R & D scientists and engineers[1], by industry: 1960-80

[In thousands]

Industry	1960	1962	1964	1966	1968	1970	1972	1973	1974	1975	1976	1977	1978	1979	1980
Total	292.0	312.0	340.2	353.2	376.7	384.2	350.2	357.7	360.0	363.3	364.4	382.8	403.7	421.0	444.5
Food and kindred products	4.7	5.4	5.7	6.2	6.3	6.3	6.5	6.6	6.4	6.8	6.9	6.9	6.9	7.8	7.5
Textiles and apparel	1.0	1.2[5]	1.2	1.4	2.5	2.9	1.8	1.9	1.8	1.8	1.8	1.7	1.7	1.8	1.8
Lumber, wood products, and furniture	.7	.6	.5	.6	.5	1.2	1.8	1.9	2.1	2.3	2.1	2.1	2.2	2.2	2.2
Paper and allied products	2.4	2.6	3.8	4.3	4.8	5.0	4.9	4.9	4.9	5.0	5.2	6.3	6.6	7.2	7.6
Chemicals and allied products	36.1	36.5	35.8	38.0	38.9	40.1	41.0	40.9	41.8	45.2	44.4	46.4	47.9	48.3	50.9
Industrial chemicals	21.8	21.6	22.2	23.3	22.3	21.5	19.1	19.1	19.1	21.1	20.1	20.6	21.5	21.6	22.1
Drugs and medicines	6.0	6.8	6.9	7.5	9.8	11.8	13.1	13.0	14.0	15.6	16.6	17.8	18.9	19.7	20.7
Other chemicals	8.3	8.1	6.7	7.2	6.8	6.8	8.8	8.8	8.7	8.5	7.8	8.0	7.4	7.0	8.1
Petroleum refining and extraction	9.2	9.1	8.1	8.9	9.2	9.9	8.3	8.2	8.2	8.4	8.6	8.9	10.0	10.7	10.7
Rubber products	5.3	5.6	6.0	5.7	6.1	7.4	6.7	7.5	7.7	8.4	8.6	9.1	7.9	8.0	9.2
Stone, clay, and glass products	(4)	3.7	3.3	3.1	4.1	4.6	4.1	4.2	4.5	4.5	4.6	4.5	5.1	5.2	5.0
Primary metals	6.9	6.0	5.1	5.5	5.9	6.5	6.4	6.0	6.4	6.3	8.1	8.4	8.1	8.2	8.4
Ferrous metals and products	3.8	3.0	2.8	3.2	3.1	3.2	3.4	3.2	3.3	3.3	3.9	3.9	3.7	3.7	3.6
Nonferrous metals and products	3.0	3.0	2.3	2.3	2.7	3.3	3.0	2.8	3.1	3.0	4.2	4.5	4.4	4.5	4.8
Fabricated metal products	7.4	7.4	7.0	6.3	5.6	5.9	6.6	6.7	7.3	7.4	6.8	7.1	7.3	7.5	7.7
Nonelectrical machinery	32.1	31.5	27.3	30.5	37.4	42.3	43.7	46.3	51.0	52.8	55.7	55.3	58.2	61.0	63.3
Office, computing, and accounting machines	(2)	(2)	(2)	(2)	(2)	(2)	(2)	30.1	34.5	36.1	38.1	37.7	39.3	42.2	43.0
Other nonelectrical machinery	(2)	(2)	(2)	(2)	(2)	(2)	(2)	16.2[5]	16.5[5]	16.7[5]	17.6[5]	17.6[5]	18.9	18.8	20.3
Electrical equipment	72.1	82.3	89.5	92.0	98.4	100.6	83.6	85.4	82.6	82.6	80.3	84.1	85.7	86.6	94.7
Radio and TV receiving equipment	(3)	(3)	(3)	(3)	1.0	1.9	2.1	1.4	1.3	1.0	1.1	.9	.9	(2)	(2)
Electronic components } Communication equipment }	40.8	52.6	60.4	62.3	67.4	64.8	53.2	9.4	9.6	10.6	10.2	13.0	14.2	(2)	(2)
Communication equipment								45.3	42.0	40.2	37.4	38.0	40.6	42.4	45.2
Other electrical equipment	31.3	29.7	29.1	29.7	30.0	33.9	28.3	29.3	29.7	30.8	31.6	32.2	30.0	29.4	31.8
Motor vehicles and other transportation equipment	17.8	20.8	23.3	24.8	24.3	25.5	29.7	29.9	29.2	27.9	27.1	30.1	32.6	34.9	36.2
Motor vehicles and motor vehicle equipment	(2)	(2)	(2)	(2)	(2)	(2)	(2)	28.2	27.4	26.0	25.4	28.2	30.7	32.9	34.4
Other transportation equipment	(2)	(2)	(2)	(2)	(2)	(2)	(2)	1.7	1.8	1.9	1.7	1.9	1.9	2.0	1.8
Aircraft and missiles	72.4	79.4	101.1	99.3	101.1	92.2	70.8	72.1	70.6	67.5	66.9	72.0	82.0	86.4	87.3
Professional and scientific instruments	10.0	9.8	10.8	12.5	14.1	15.0	15.2	16.3	17.5	17.9	18.8	20.5	22.2	24.0	28.4
Scientific and mechanical measuring instruments	5.5	4.8	3.8	3.8	3.8	4.1	4.7	5.3	5.6	5.9	6.7	7.2	7.9	9.0	11.4
Optical, surgical, photographic, and other instruments	4.5	5.0	7.0	8.7	10.3	10.9	10.5	11.0	11.9	12.0	12.1	13.3	14.3	15.0	17.0
Other manufacturing industries	13.8	3.1	2.0	2.3	2.4	2.6	3.6	3.6	3.7	3.7	4.2	4.5	4.6	4.8	4.3
Nonmanufacturing industries	(4)	7.0	9.8	11.7	15.1	16.3	15.7	15.3	14.4	14.9	14.6	15.3	14.7	16.4	19.3

[1]Full-time equivalent, as of January of each year.
[2]Not separately available but included in total.
[3]Included in other electrical equipment.
[4]Included in other manufacturing industries.
[5]Estimated.

NOTE: Preliminary data are shown for 1979 and 1980.

SOURCES: 1960-1966: National Science Foundation, *Research and Development in Industry, 1971* (NSF 73-305), p. 47; 1968-1978: National Science Foundation, *Research and Development in Industry, 1978* (NSF 80-307), p. 31; 1979-1980: National Science Foundation, preliminary data.

See figure 4-6.

Appendix table 4-9. Industry's expenditures for R & D in other sectors: 1960-81

[Dollars in millions]

Year	Current dollars		Constant 1972 dollars[1]	
	Universities and colleges	Nonprofit institutions	Universities and colleges	Nonprofit institutions
1960	$40	$48	$58	$70
1961	40	49	58	71
1962	40	54	57	76
1963	41	55	57	77
1964	40	55	55	76
1965	41	62	55	83
1966	42	70	55	91
1967	48	74	61	94
1968	55	81	67	98
1969	60	93	69	107
1970	61	95	67	104
1971	70	98	73	102
1972	74	101	74	101
1973	84	105	79	99
1974	96	115	84	100
1975	113	125	90	100
1976	123	135	93	102
1977	139	150	99	107
1978	170	165	113	110
1979 (prelim.)	194	180	119	111
1980 (est.)	225	200	127	113
1981 (est.)	240	225	123	115

[1]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCES: 1960-1978: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), p. 25; 1979-1981: National Science Foundation, preliminary data.

See figure 4-7.

Science Indicators—1980

Appendix table 4-10. Journal publications[1] written with industry participation and with joint university-industry participation: 1973 and 1979

Field[2]	Number of publications: All industry participation 1973	1979	University-industry participation 1973	1979	Percent university-industry 1973	1979
All fields	12,180	10,057	1,566	1,710	13	17
Clinical medicine	1,600	1,391	329	356	21	26
Biomedicine	618	601	117	154	19	26
Biology	446	401	86	125	19	31
Chemistry	1,983	1,660	185	184	9	11
Physics	1,911	1,948	246	327	13	17
Earth and space sciences	358	389	102	101	28	26
Engineering and technology	5,130	3,562	463	424	9	12
Mathematics	134	105	38	39	28	37

[1]Includes articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.
[2]See appendix table 1-13 for a description of the subfields included in these fields.

NOTE: Every publication written with industry or university-industry participation is counted as one, regardless of the number of authors.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 4-8.

Science Indicators—1980

Appendix table 4-11. Number of journal publications[1] jointly written in industry and another sector, compared with all industry-originated publications and with industry-university jointly written publications: 1973 and 1979

Field[2]	Number of industry-other sector publications[3] 1973	1979	Industry-other sector publications as a percent of all industry-participation publications 1973	1979	University-industry publications as a percent of all industry-other sector publications 1973	1979
All fields	2658	2870	21.8	28.5	58.9	59.6
Clinical medicine	570	591	35.6	42.5	57.7	60.3
Biomedicine	194	244	31.4	40.6	60.3	63.1
Biology	122	170	27.4	42.4	70.5	73.5
Chemistry	300	272	15.1	16.4	61.7	67.6
Physics	382	501	20.0	25.7	64.4	62.3
Earth and space sciences	141	168	39.4	43.2	72.3	60.1
Engineering and technology	907	882	17.7	24.8	51.0	48.1
Mathematics	42	42	31.3	40.0	90.5	92.9

[1]Includes the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.
[2]See appendix table 1-13 for a description of the subfields included in these fields.
[3]Every publication written with industry-other sector participation is counted as one regardless of the number of authors.

SOURCE: Computer Horizons, Inc., unpublished data, and appendix table 4-10.

See figure 4-8.

Science Indicators—1980

Appendix table 4-12. Distribution of scientific and technical publications[1] by all U.S. authors, by industry authors, and by industry and university joint authors, for different fields and levels of research: 1979

Field[2]	All U.S. authors			Industry authors			University-industry authors		
	Applied research	Basic research	Percent basic	Applied research	Basic research	Percent basic	Applied research	Basic research	Percent basic
Clinical medicine	20,053	13,923	41.0	387	689	64.0	197	159	44.7
Biomedicine	582	17,066	96.7	13	447	97.2	6	148	96.1
Biology	3,186	7,367	69.8	187	121	39.3	68	57	45.6
Chemistry	554	8,628	94.0	200	1,311	86.8	11	173	94.0
Physics	389	10,606	96.5	148	1,507	91.1	16	311	95.1
Earth and space sciences	628	4,540	87.9	143	158	52.7	20	81	80.2
Engineering and technology	7,714	1,304	14.5	2,955	259	8.1	396	28	6.6
Mathematics	350	2,489	87.7	30	50	62.5	12	27	69.2

[1]Includes the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2]See appendix table 1-13 for a description of the subfields included in these fields.

NOTE: Every publication written with industry or university-industry participation is counted as one, regardless of the number of authors.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 4-9.

Science Indicators—1980.

Appendix table 4-13. Relative citation ratios[1] by field for citations between industry- and university-originated journal publications[2]: 1973-1977

Field[3]	Year of cited article[4]				
	1973	1974	1975	1976	1977
Citations from university to industry:					
Clinical medicine	.57	.49	.47	.49	.50
Biomedicine	.62	.63	.79	.63	.67
Biology	.57	.42	.65	.67	.47
Chemistry	.37	.36	.33	.38	.40
Physics	.67	.62	.63	.55	.58
Earth and space sciences	.54	.51	.36	.47	.37
Engineering and technology	.45	.44	.43	.44	.39
Mathematics	.74	.64	1.09	.66	NA
Citations from industry to university:					
Clinical medicine	.72	.71	.70	.66	.51
Biomedicine	.71	.69	.66	.65	.67
Biology	.76	.77	.65	.62	.49
Chemistry	.55	.57	.56	.55	.62
Physics	.47	.48	.44	.49	.45
Earth and space sciences	.74	.74	.74	.67	.71
Engineering and technology	.56	.52	.51	.52	.46
Mathematics	.68	.66	.67	.62	NA

[1]A citation ratio of 1.00 would mean that the cited sector received a share of citations equal to its share of published articles. A lower ratio indicates that articles from the cited sector are cited less often than their numbers would warrant. For example, industry's clinical medicine articles published in 1973 received a share of citations from subsequent university articles that was 57 percent of industry's share of all clinical medicine articles published in that year.

[2]Includes the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. For the size of this data base, see appendix table 1-12.

[3]See appendix table 1-13 for a description of the subfields included in these fields.

[4]Ratios for 1975-77 are corrected for expected future citations to articles published in those years.

SOURCE: Computer Horizons, Inc., unpublished data.

See table 4-4 in text.

Appendix table 4-14. U.S. patents granted, by nationality of inventor: 1960-79

Year	By date of application			By date of grant		
	All U.S. patents	To U.S. inventors	To foreign inventors	All U.S. patents	To U.S. inventors	To foreign inventors
1960	NA	NA	NA	47,170	39,472	7,698
1961	NA	NA	NA	48,368	40,154	8,214
1962	NA	NA	NA	55,691	45,579	10,112
1963	NA	NA	NA	45,679	37,174	8,505
1964	NA	NA	NA	47,375	38,411	8,964
1965	54,840	42,205	12,635	62,857	50,332	12,525
1966	59,661	45,004	14,657	68,405	54,634	13,771
1967	60,007	44,153	15,854	65,652	51,274	14,378
1968	62,943	45,315	17,628	59,103	45,783	13,320
1969	65,828	46,364	19,464	67,559	50,397	17,162
1970	65,893	45,805	20,088	64,429	47,075	17,354
1971	66,284	45,516	20,768	78,316	55,976	22,340
1972	63,262	42,351	20,911	74,806	51,516	22,340
1973	66,141	42,630	23,511	74,142	51,503	22,639
1974	66,085	41,607	24,478	76,278	50,645	25,633
1975	65,017	41,668	23,349	71,998	46,708	25,290
1976	63,631	40,229	23,402	70,218	44,271	25,947
1977	NA	NA	NA	65,269	41,484	23,785
1978	NA	NA	NA	66,079	41,233	24,846
1979	NA	NA	NA	48,841[1]	30,061[1]	18,780[1]

[1]Patent counts for 1979 are spuriously low because of a lack of funds in the Patent Office for printing and issuing patents.

NA = Not available.

SOURCES: 1960-65: Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, *Special Report: A Profile of U. S. Patent Activity;* 1966-79: Office of Technology Assessment and Forecast, U. S. Patent and Trademark Office, *Indicators of Patent Output of U. S. Industry, IV (1963-1979),* June 1980.

See figure 4-10.

Science Indicators—1980

Appendix table 4-15. U.S. patents granted to U.S. inventors, by type of owner: 1961-79

Year	By date of application					By date of patent grant				
	All patents	U.S. corp.	U.S. Gov't.	U.S. individual[1]	Foreign[2]	All patents	U.S. corp.	U.S. Gov't	U.S. individual[1]	Foreign[2]
1961	NA	NA	NA	NA	NA	40,154	27,383	1,460	11,233	79
1962	NA	NA	NA	NA	NA	45,579	31,377	1,276	12,817	109
1963	NA	NA	NA	NA	NA	37,174	25,722	1,017	10,358	77
1964	NA	NA	NA	NA	NA	38,411	26,808	1,174	10,336	93
1965	42,205	30,155	1,426	10,475	149	50,332	35,698	1,522	13,032	80
1966	45,004	32,887	1,481	10,412	224	54,634	39,891	1,512	13,050	181
1967	44,153	32,040	1,562	10,313	238	51,274	36,745	1,726	12,634	169
1968	45,315	33,084	1,707	10,242	282	45,783	33,351	1,458	10,768	206
1969	46,364	33,737	1,807	10,505	315	50,397	37,160	1,810	11,208	219
1970	45,805	33,028	1,614	10,852	311	47,075	35,067	1,763	9,968	277
1971	45,516	32,594	1,581	11,062	279	55,976	40,945	2,135	12,462	434
1972	42,351	30,558	1,507	10,055	231	51,516	37,861	1,768	11,558	329
1973	42,630	30,467	1,375	10,561	227	51,503	36,860	2,082	12,293	268
1974	41,607	29,955	1,556	9,839	257	50,645	36,137	1,735	12,468	305
1975	41,668	29,886	1,467	10,121	194	46,708	33,408	1,882	11,163	255
1976	40,229	28,121	1,292	10,593	223	44,271	32,139	1,807	10,070	255
1977	NA	NA	NA	NA	NA	41,484	29,563	1,480	10,227	214
1978	NA	NA	NA	NA	NA	41,233	29,394	1,226	10,361	252
1979	NA	NA	NA	NA	NA	30,061[3]	21,125[3]	946[3]	7,794[3]	196[3]

[1]Includes unassigned patents.
[2]Comprises patents assigned to foreign corporations, governments, and individuals.
[3]Patent counts for 1979 are spuriously low because of a lack of funds in the Patent Office for printing and issuing patents.

NA = Not available.

SOURCES: 1960-65: Office of Technology Assessment and Forecast, U. S. Patent and Trademark Office, *Special Report: A Profile of U. S. Patent Activity;* 1966-79: Office of Technology Assessment and Forecast, U. S. Patent and Trademark Office, *Indicators of Patent Output of U. S. Industry, IV (1963-1979),* June 1980.

See figure 4-11.

Science Indicators—1980

Appendix table 4-16. Distribution of U.S. patents due to U.S. inventors, by product field and class of ownership, for patents granted in 1978

Product field	Percent U.S. corporations	Percent U.S. Government	Percent U.S. individuals[1]
All product fields	72	3	25
Food and kindred products	78	5	17
Textile mill products	85	3	11
Chemicals and allied products	92	3	5
Chemicals, except drugs and medicines	92	3	5
Basic industrial inorganic and organic chemicals	93	3	3
Industrial inorganic chemicals	87	5	7
Industrial organic chemicals	94	3	2
Plastics materials and synthetic resins	92	2	6
Agricultural chemicals	92	2	6
All other chemicals	86	5	9
Soap, detergents, and cleaning preparations; perfumes, cosmetics, and other toilet preparations	91	2	6
Paints, varnishes, lacquers, enamels, and allied products	80	2	15
Miscellaneous chemical products	82	8	9
Drugs and medicines	92	1	6
Petroleum and natural gas extraction and petroleum refining	86	2	9
Rubber and miscellaneous plastics products	73	2	25
Stone, clay, glass, and concrete products	75	2	22
Primary metals	75	3	19
Primary ferrous products	72	3	24
Primary and secondary nonferrous products	78	4	14
Fabricated metal products	60	2	37
Machinery except electrical	65	2	29
Engines and turbines	56	5	39
Farm and garden machinery and equipment	56	1	43
Construction, mining, and material handling machinery and equipment	62	1	37
Metal working machinery and equipment	65	1	33
Office computing and accounting machines	84	3	13
Other machinery, except electrical	70	1	28
Special industry machinery, except metal working machinery	74	1	24
General industrial machinery and equipment	69	1	30
Refrigeration and service industry machinery	62	1	37
Miscellaneous machinery, except electrical	68	1	31
Electrical and electronic machinery, equipment and supplies	77	5	17
Electrical equipment, except communication equipment	78	4	18
Electrical transmission and distribution equipment	80	6	13
Electrical industrial apparatus	84	3	13
Other electrical machinery, equipment and supplies	75	3	22
Household appliances	65	1	33
Electrical lighting and wiring equipment	74	2	24
Miscellaneous electrical machinery, equipment, and supplies	81	5	14
Communication equipment and electronic components	77	7	15
Radio and television receiving equipment, except communication types	79	6	14
Electronic components and accessories and communication equipment	77	7	15
Transportation equipment	56	6	38
Motor vehicles and other transportation equipment, except aircraft	56	6	38
Motor vehicles and motor vehicle equipment	59	2	39
Guided missiles and space vehicles and parts	65	17	18
Other transportation equipment	62	1	36
Ship and boat building and repairing	48	3	47
Railroad equipment	83	1	16
Motorcycles, bicycles, and parts	69	0	31
Miscellaneous transportation equipment	67	1	32
Ordnance, except missiles	38	27	35
Aircraft and parts	55	4	41
Professional and scientific instruments	69	4	26

[1]Includes unassigned patents.

SOURCE: Calculated from Office of Technology Assessment and Forecast, U. S. Patent and Trademark Office, *Indicators of Patent Output of U. S. Industry, IV (1963-1979)*, June 1980.

See table 4-5 in text.

Appendix table 4-17. Number of U.S. patents due to U.S. inventors, by product field, for patents granted in 1978

Product field	1978	Average percent change per year, 1968-1978
All product fields	41,233	-0.4
Food and kindred products	336	2.8
Textile mill products	441	1.6
Chemicals and allied products	7,176	.4
Chemicals, except drugs and medicines	7,054	.3
Basic industrial inorganic and organic chemicals	3,309	- .3
Industrial inorganic chemicals	931	-1.0
Industrial organic chemicals	2,671	- .2
Plastics materials and synthetic resins	2,011	-1.7
Agricultural chemicals	1,246	7.4
All other chemicals	800	3.5
Soap, detergents, and cleaning preparations, perfumes, cosmetics, and other toilet preparations	343	8.7
Paints, varnishes, lacquers, enamels, and allied products	46	.8
Miscellaneous chemical products	456	2.0
Drugs and medicines	1,481	6.0
Petroleum and natural gas extraction and petroleum refining	846	- .6
Rubber and miscellaneous plastics products	2,408	- .9
Stone, clay, glass, and concrete products	1,041	2.2
Primary metals	442	- .3
Primary ferrous products	285	-1.1
Primary and secondary nonferrous products	291	- .3
Fabricated metal products	5,585	-1.6
Machinery, except electrical	11,530	-1.3
Engines and turbines	1,176	1.3
Farm and garden machinery and equipment	1,180	- .6
Construction, mining, and material handling machinery and equipment	1,991	-1.2
Metal working machinery and equipment	1,023	-1.4
Office computing and accounting machines	1,388	.9
Other machinery, except electrical	6,759	-2.1
Special industry machinery, except metal working machinery	2,623	-2.0
General industrial machinery and equipment	3,431	-2.4
Refrigeration and service industry machinery	889	-1.9
Miscellaneous machinery, except electrical	632	1.5
Electrical and electronic machinery, equipment and supplies	8,074	- .5
Electrical equipment, except communication equipment	4,262	-1.9
Electrical transmission and distribution equipment	1,390	-2.1
Electrical industrial apparatus	1,076	-3.4
Other electrical machinery, equipment and supplies	2,239	-1.9
Household appliances	641	-3.6
Electrical lighting and wiring equipment	483	-2.1
Miscellaneous electrical machinery, equipment, and supplies	1,107	- .4
Communication equipment and electronic components	4,533	.5
Radio and television receiving equipment, except communication types	748	.9
Electronic components and accessories and communication equipment	4,464	.6
Transportation equipment	2,816	.3
Motor vehicles and other transportation equipment	2,651	.5
Motor vehicles and motor vehicle equipment	1,645	1.3
Guided missiles and space vehicles and parts	260	-3.2
Other transportation equipment	771	- .2
Ship and boat building and repairing	223	-1.3
Railroad equipment	370	-1.1
Motorcyles, bicycles, and parts	68	- .4
Miscellaneous transportation equipment	458	.2
Ordnance, except missiles	279	1.6
Aircraft and parts	974	2.2
Professional and scientific instruments	5,178	3.0

SOURCE: Calculated from Office of Technology Assessment and Forecast, U. S. Patent and Trademark Office, *Indicators of Patent Output of U. S. Industry, IV (1963-1979)*. "All product fields" from appendix table 4-14.

NOTE: The average annual rate of change in patenting is equal to 2/11 $(X/X_0 - 1)$, where X is the average annual rate of patenting from 1969 to 1978 and X_0 is the average from 1967 to 1969. This method of calculation reduces the effect of year-to-year oscillations in the data.

See table 4-6 in text.

Appendix table 4-18. Maximum addition rate for computers introduced in each year: 1951-79

Computer	Year of introduction	Addition rate (thousands of operations per second)
UNIVAC U1	1951	1.90
IBM 650	1954	.69
IBM 704	1955	13.89
CDC LGP-30	1956	.44
UNIVAC U2	1957	2.27
IBM 709	1958	13.88
IBM 7090	1959	76.30
CDC 1604	1960	46.30
IBM 7030	1961	285.70
IBM 7094	1962	100.00
CDC 3600	1963	166.70
CDC 6600	1964	3,333.30
UNIVAC 1108	1965	434.80
IBM 360/44	1966	100.00
BGH 3500	1967	26.70
BGH 6700	1969	5,000.00
DEC PDP-11	1970	416.60
IBM 370/165	1971	714.30
UNIVAC 1110	1972	3,333.00
DEC 11-40	1973	352.00
HP 21MXM	1974	526.30
IBM 370/168	1975	6,250.00
IBM S1/5	1976	413.20
IBM 370/148	1977	807.80
IBM 3033	1978	12,500.00
IBM 4341	1979	1,667.00

SOURCE: The Futures Group, Glastonbury, Ct., preliminary report to the Science Indicators Unit, National Science Foundation, August 1980.

See figure 4-12.

Science Indicators—1980

Appendix table 4-19. Performance indices of computers with higher indices than any previous computer, by year of computer introduction: 1951-78

Computer	Year	Speed (Kops/sec)	Cost (Kops/$)	Capacity (Kbytes)	Index
UNIVAC U1	1951	0.27	7	8	0.011
IBM 650	1954	.29	45	20	.027
IBM 704	1955	3.79	50	192	.246
IBM 709	1958	10.23	91	192	.265
IBM 7090	1959	45.47	443	197	.378
CDC 1604	1960	20.40	374	256	.381
IBM 7094	1962	95.90	842	197	.526
CDC 3600	1963	74.90	849	2,048	2.731
CDC 6600	1964	4,090.00	33,988	1,280	13.694
BGH 6700	1969	8,886.00	81,540	6,144	34.170
CDC CYB/76	1972	10,220.00	38,632	5,770	35.479
IBM 3033	1978	19,019.00	65,932	16,384	72.675

State-of-the-art factors

Factor	Units	Weight
X_1: Speed	Kops/sec	$K_1 = 0.5$
X_2: Cost	Kops/$	$K_2 = .3$
X_3: Capacity	Kbytes	$K_3 = .2$

$$\text{Index} = 100 \left[K_1 \left(\frac{X_1}{X_1^*}\right) + K_2 \left(\frac{X_2}{X_2^*}\right) + K_3 \left(\frac{X_3}{X_3^*}\right) \right]$$

X_i^* = maximum value of the parameter
X_1^* = 19,019 Kops/sec (IBM 3033)
X_2^* = 739,300 Kops/dollar (HP21MXM)
X_3^* = 16,384 Kbytes (IBM 3033)

SOURCE: The Futures Group, Glastonbury, Ct., *Research into Technology Output Measures,* Report to the Science Indicators Unit, National Science Foundation, November 1980, p. 123.

See figure 4-13.

Appendix table 4-20. Performance index of various antibiotics against one bacterium, by year of antibiotic introduction: 1943-1979

[Staphylococcus Aureus]

Antibiotic	Year	C(75)	T	X_1	X_2	X_3	Index
Penicillin	1943	2.36	0.65	24	12	24	11
Streptomycin	1946	63.75	2.40	3	12	24	0.37
Chloramphenicol	1949	4.64	2.70	6	12	24	6
Erythromycin	1952	1.80	1.20	24	18	24	17
Tetracycline	1953	.08	9.00	6	15	15	713
Vancomycin	1958	2.57	6.00	6	12	15	15
Methicillin	1960	1.58	.40	24	18	15	15
Oxacillin	1962	.32	.50	24	18	15	77
Ampicillin	1963	2.16	1.31	24	12	24	14
Cephalothin	1964	.21	.85	12	12	6	74
Nafcillin	1964	.44	.50	24	18	6	48
Cloxacillin	1965	.11	.40	24	18	15	218
Gentamicin	1966	.22	2.00	6	12	15	90
Cephaloridine	1968	.04	1.12	12	12	6	461
Dicloxacillin	1968	.11	.70	24	18	6	209
Clindamycin	1970	.02	2.40	3	12	15	983
Cephalexin	1971	1.31	.90	12	18	6	13
†Rosamicin	1973	.18	4.00	12	12	15	184
Torramycin	1974	.35	2.00	6	12	15	62
Sisomicin	1975	.17	2.03	6	12	6	105
†Netilmicin	1976	.17	2.50	6	12	6	115
†Piperacillin	1977	.63	1.20	24	12	15	42
Cefamandole	1978	.65	1.00	12	12	6	25
Cefaclor	1979	1.63	1.00	12	18	6	11

† Indicates not available in the U.S. market.

State-of-the-art factors

Factor	Units	Weight
C: Concentration	μg/ml	—
T: Biological half-life	hours	$K_1 = 0.286$
X_1: Side-effects scale	—	$K_2 = .357$
X_2: Ease-of-administration scale	—	$K_3 = .214$
X_3: Cost scale	—	$K_4 = .143$

$$I = \left(\frac{C^*}{C}\right)\left[K_1\left(\frac{T}{T^*}\right) + K_2\left(\frac{X_1}{X_1^*}\right) + K_3\left(\frac{X_2}{X_2^*}\right) + K_4\left(\frac{X_3}{X_3^*}\right)\right]$$

Index = 100 I(N/ΣI)
where N is the total number of antibiotics being compared, and the summation is made over that total number.

* Refers to value of same factor for cefamandole.

SOURCE: The Futures Group, Glastonbury, Ct., preliminary report to the Science Indicators Unit, National Science Foundation, August 1980.

See figure 4-14.

Appendix table 4-21. Composite performance indices of antibiotics with higher indices than any previous antibiotic, by year of introduction: 1941-75

Antibiotic	Year	Index
Sulfa	1941	13
Penicillin	1943	248
Polymyxim B	1951	490
Colistin	1962	1,354
Cloxacillin	1965	1,811
Dicloxacillin	1968	1,850
†Rosamicin	1973	1,858
Sisomicin	1975	3,397

†Indicates not available in the U. S. market.

NOTE: The index for each antibiotic is obtained by weighting its indices for all bacteria, as obtained from the equation on appendix table 4-20, according to the frequencies of occurrence of those bacteria.

SOURCE: The Futures Group, Glastonbury, Ct., preliminary report to the Science Indicators Unit, National Science Foundation, August 1980.

See figure 4-15.

Science Indicators—1980

Appendix table 4-22. Labor productivity[1] for selected industries: 1960-79

Industry	1960	1962	1964	1966	1968	1970	1972	1973	1974	1975	1976	1977	1978	1979 (prelim.)
All manufacturing	0.775	0.827	0.924	0.963	1.000	1.013	1.115	1.146	1.089	1.147	1.197	1.233	1.240	1.251
Food and kindred products	.778	.828	.912	.979	1.000	1.075	1.147	1.164	1.090	1.242	1.312	1.377	1.408	1.411
Tobacco manufactures	.808	.899	.868	.929	1.000	1.095	1.266	1.242	1.278	1.370	1.435	1.488	1.457	1.561
Textile mill products	.629	.678	.916	.998	1.000	1.114	1.175	1.161	1.188	1.236	1.255	1.341	1.406	1.465
Apparel and other fabric products	.835	.835	.885	.951	1.000	1.008	1.121	1.226	1.211	1.337	1.348	1.422	1.484	1.527
Lumber and wood products	.594	.593	.845	.894	1.000	1.099	1.067	1.050	1.115	1.186	1.167	1.143	1.124	1.126
Furniture and fixtures	.892	.905	.961	.999	1.000	.981	1.088	1.096	1.078	1.144	1.210	1.189	1.195	1.222
Paper and allied products	.805	.858	.918	.957	1.000	.998	1.198	1.331	1.260	1.200	1.268	1.314	1.340	1.392
Printing, publishing, and allied industries	.831	.863	.994	.998	1.000	.967	1.024	1.078	1.023	1.019	1.067	1.086	1.107	1.106
Chemicals and allied products	.690	.749	.873	.924	1.000	1.052	1.213	1.275	1.173	1.217	1.297	1.339	1.373	1.412
Petroleum refining and related industries	.658	.791	.886	.942	1.000	1.050	1.077	1.153	1.107	1.152	1.180	1.352	1.303	1.277
Rubber and miscellaneous plastic products	.793	.866	.955	.945	1.000	.992	1.070	1.102	1.006	1.094	1.128	1.081	1.113	1.114
Leather and leather products	.845	.905	.975	1.014	1.000	1.025	1.030	1.181	1.171	1.217	1.250	1.260	1.283	1.270
Stone, clay, glass, and concrete products	.860	.917	1.003	.988	1.000	1.007	1.060	1.080	.995	1.042	1.156	1.137	1.178	1.182
Primary metals industries	.849	.879	.971	1.020	1.000	.933	1.011	1.064	1.049	.985	.955	.920	.929	.914
Fabricated metal products	.841	.904	.939	.971	1.000	.974	1.047	1.068	.984	1.021	1.082	1.126	1.107	1.110
Nonelectrical machinery	.860	.934	.988	.990	1.000	1.041	1.132	1.142	1.056	1.127	1.159	1.152	1.137	1.149
Electrical and electronic machinery, equipment, and supplies	.661	.731	.848	.935	1.000	1.055	1.223	1.260	1.231	1.290	1.326	1.380	1.421	1.408
Motor vehicles and motor vehicle equipment	.681	.731	.841	.920	1.000	.884	1.098	1.017	1.007	1.132	1.312	1.452	1.480	1.424
Aircraft and parts	.772	.858	.959	.944	1.000	.991	1.109	1.045	.965	.940	.938	.927	.957	.942
Professional and scientific instruments	.759	.805	.861	.955	1.000	1.013	1.117	1.131	1.017	1.146	1.170	1.135	1.115	1.112
Miscellaneous manufacturing industries	.823	.871	.897	.924	1.000	1.043	1.181	1.167	1.101	1.245	1.250	1.421	1.431	1.485

[1]Real output per hour of production and nonproduction employed labor (1968 = 1.000).

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, unpublished data.

See table 4-8 in text.

Appendix table 5-1. Scientists and engineers by field, sex and labor force status: 1974-78

Field and sex	Total			In the labor force			Outside the labor force		
	1974	1976	1978	1974	1976	1978	1974	1976	1978
All S/E fields	2,481,800	2,705,800	2,741,400	2,288,000	2,451,700	2,507,600	193,800	254,100	233,800
Men	2,265,000	2,455,800	2,475,300	2,109,700	2,240,000	2,270,400	160,300	215,800	204,900
Women	216,800	250,000	266,100	183,300	211,700	237,200	33,500	38,300	28,900
Physical scientists	247,900	280,600	254,600	206,500	237,300	216,700	41,400	43,300	37,900
Men	227,200	245,100	231,800	189,900	215,800	200,700	37,300	38,300	31,100
Women	20,700	26,500	22,800	16,600	21,500	16,000	4,100	5,100	6,800
Mathematical scientists	101,000	110,200	107,800	84,500	92,200	89,800	16,500	18,000	18,000
Men	81,000	87,200	88,000	70,600	76,000	71,800	10,400	11,200	16,200
Women	20,000	22,900	19,800	13,900	16,200	18,000	6,100	6,800	1,800
Computer specialists	170,000	179,900	237,500	167,100	173,500	234,600	2,900	6,400	2,900
Men	135,400	143,500	194,800	135,400	139,500	193,900	(2)	4,000	900
Women	34,600	36,400	42,700	31,700	34,000	40,600	2,900	2,400	2,100
Environmental scientists[1]	79,000	85,700	80,800	71,500	77,400	73,900	7,500	8,300	6,900
Men	73,700	79,300	72,200	67,100	73,000	66,200	6,600	6,300	6,000
Women	5,200	6,400	8,600	4,400	4,400	7,800	900	2,000	900
Life scientists	266,000	314,100	327,600	243,400	286,300	295,800	22,600	27,800	31,800
Men	214,100	253,300	255,400	197,400	232,700	231,500	16,700	20,600	23,900
Women	51,900	60,800	72,200	46,000	53,700	64,300	5,900	7,200	7,900
Social scientists	217,000	237,200	205,100	192,400	211,400	188,500	24,600	25,600	16,600
Men	164,000	179,200	162,800	147,100	162,100	150,600	16,900	17,100	12,200
Women	53,000	58,000	42,200	45,300	49,300	37,800	7,700	8,600	4,400
Psychologists	109,300	122,900	131,700	94,000	105,700	123,200	15,300	17,200	8,500
Men	84,200	92,300	95,700	73,000	80,000	91,100	11,200	12,300	4,600
Women	25,100	30,700	36,000	21,000	25,700	32,100	4,100	4,900	3,900
Engineers	1,291,600	1,375,200	1,396,400	1,228,600	1,268,000	1,285,000	63,000	107,200	111,300
Men	1,284,900	1,366,900	1,374,600	1,224,200	1,261,000	1,264,500	60,700	105,900	110,100
Women	6,700	8,300	21,700	4,400	7,000	20,500	2,300	1,300	1,000

[1]Includes earth scientists, oceanographers, and atmospheric scientists.
[2]Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCES: National Science Foundation, *U.S. Scientists and Engineers* (biennial series, 1976-78).

See figure 5-18.

Appendix table 5-2. Scientists and engineers in the labor force by field, sex and employment status: 1974-78

Field and sex	Total			Total employed: In S/E jobs			Total employed: Not in S/E jobs			Unemployed but seeking employment		
	1974	1976	1978	1974	1976	1978	1974	1976	1978	1974	1976	1978
All S/E fields	2,248,200	2,377,100	2,473,200	NA	2,090,300	2,091,900	NA	286,800	381,300	39,800	74,600	34,400
Men	2,072,100	2,179,900	2,241,700	NA	1,914,400	1,957,400	NA	265,600	284,300	32,600	60,100	28,700
Women	176,100	197,200	231,500	NA	175,900	134,600	NA	21,300	97,000	7,200	14,500	5,700
Physical scientists	201,400	227,400	212,400	NA	189,400	184,700	NA	38,000	27,600	5,100	9,900	4,300
Men	185,500	207,500	197,400	NA	176,400	174,400	NA	31,100	22,900	4,400	8,400	3,400
Women	15,900	19,900	15,000	NA	13,100	10,300	NA	6,900	4,700	700	1,500	1,000
Mathematical scientists	82,800	88,300	88,400	NA	85,700	42,900	NA	2,600	45,600	1,700	3,900	1,400
Men	69,300	72,700	70,900	NA	70,300	38,100	NA	2,300	32,700	1,300	3,300	900
Women	13,500	15,600	17,500	NA	15,300	4,800	NA	300	12,800	400	600	500
Computer specialists	166,200	172,300	234,000	NA	167,200	231,400	NA	5,200	2,500	900	1,100	600
Men	134,900	138,700	193,400	NA	134,400	191,100	NA	4,300	2,200	500	800	600
Women	31,300	33,600	40,600	NA	32,700	40,300	NA	900	300	400	400	100
Environmental scientists[1]	69,100	74,800	72,300	NA	52,000	62,400	NA	22,900	9,900	2,400	2,600	1,700
Men	64,800	71,100	64,600	NA	49,900	57,500	NA	21,200	7,100	2,300	1,800	1,600
Women	4,300	3,700	7,700	NA	2,100	5,000	NA	1,600	2,700	100	700	100
Life scientists	238,600	277,500	291,000	NA	224,900	201,800	NA	52,600	89,100	4,800	8,800	4,900
Men	193,400	226,000	227,800	NA	176,400	165,600	NA	49,600	62,100	4,000	6,600	3,800
Women	45,200	51,400	63,200	NA	48,500	36,200	NA	2,900	26,900	800	2,200	1,200
Social scientists	187,900	198,300	186,000	NA	163,600	96,200	NA	34,700	89,800	4,500	13,100	2,500
Men	144,500	153,200	149,500	NA	124,900	89,000	NA	28,300	60,500	2,700	9,000	1,100
Women	43,400	45,200	36,400	NA	38,700	7,200	NA	6,400	29,300	1,800	4,200	1,400
Psychologists	89,600	97,800	120,900	NA	84,200	71,200	NA	13,500	49,700	4,400	8,000	2,300
Men	71,500	76,700	89,700	NA	64,600	58,200	NA	12,100	31,500	1,500	3,300	1,400
Women	18,100	21,100	31,200	NA	19,700	13,100	NA	1,400	18,200	2,900	4,700	900
Engineers	1,212,600	1,240,700	1,268,400	NA	1,123,400	1,201,200	NA	117,300	67,200	16,000	27,200	16,700
Men	1,208,300	1,234,000	1,248,500	NA	1,117,600	1,183,400	NA	116,500	65,100	15,900	26,900	16,000
Women	4,300	6,700	19,800	NA	5,800	17,800	NA	900	2,100	100	300	700

[1]Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

NA: Not available.

SOURCES: National Science Foundation, *U.S. Scientists and Engineers* (biennial series, 1976-78) and unpublished data.

See figures 5-1, 5-6 and 5-18.

Appendix table 5-3. Doctoral scientists and engineers by field, sex and labor force status: 1973-79

Field and sex	Total population			In labor force			Total employed			Outside labor force		
	1973	1977	1979	1973	1977	1979	1973	1977	1979	1973	1977	1979
All S/E fields	238,900	303,300	332,300	222,900	297,500	316,700	220,400	284,200	313,800	10,700	13,100	15,600
Men	218,000	271,600	294,400	205,300	259,100	282,400	203,500	256,700	280,400	8,300	10,200	12,000
Women	20,900	31,700	37,900	17,600	28,500	34,300	17,000	27,500	33,300	2,400	2,900	3,600
Physical scientists	53,000	62,100	64,300	49,400	58,200	60,900	48,500	57,500	60,200	2,700	3,300	3,400
Men	50,500	58,500	60,600	47,300	55,100	57,600	46,600	54,500	57,000	2,300	2,900	3,000
Women	2,500	3,500	3,700	2,000	3,100	3,200	1,900	2,900	3,100	400	400	400
Mathematical scientists	13,100	15,400	16,100	12,300	14,700	15,400	12,100	14,600	15,300	500	500	700
Men	12,100	14,200	14,800	11,500	13,700	14,200	11,400	13,500	14,200	400	400	600
Women	1,000	1,200	1,300	800	1,000	1,100	800	1,000	1,100	100	100	100
Computer specialists	2,700	5,800	6,800	2,700	5,800	6,800	2,700	5,800	6,700	20	30	20
Men	2,600	5,600	6,400	2,600	5,500	6,400	2,600	5,500	6,400	20	27	13
Women	100	200	400	100	200	400	100	200	400	([1])	([1])	([1])
Environmental scientists[2]	10,900	13,500	15,100	10,400	13,100	14,700	10,300	13,000	14,600	300	400	400
Men	10,600	13,100	14,400	10,200	12,700	14,000	10,100	12,600	14,000	300	300	400
Women	300	500	700	300	400	600	300	400	600	([1])	([1])	([1])
Life scientists	63,600	78,300	86,300	58,600	72,900	81,000	58,000	71,900	80,100	3,500	4,700	5,400
Men	55,800	67,600	73,200	52,200	63,600	69,400	51,900	62,900	68,900	2,500	3,400	3,800
Women	7,800	10,800	13,100	6,400	9,300	11,500	6,100	9,000	11,100	1,000	1,400	1,600
Social scientists	31,200	45,800	52,000	28,400	43,300	49,200	28,100	42,700	48,700	1,700	2,100	2,800
Men	27,700	39,200	43,800	25,400	27,000	41,700	25,200	36,800	41,400	1,400	1,700	2,200
Women	3,500	6,600	8,100	3,000	6,200	7,400	2,900	6,000	7,200	300	400	600
Psychologists	27,200	35,700	40,300	25,200	34,100	38,400	24,900	33,700	38,000	1,200	1,200	1,800
Men	21,500	27,200	30,100	20,200	26,300	29,200	20,100	26,100	28,800	700	600	1,100
Women	5,600	8,500	10,200	4,900	7,800	9,400	4,800	7,600	9,200	500	600	700
Engineers	37,300	46,500	51,600	36,100	45,300	50,600	35,800	45,000	50,300	700	900	1,100
Men	37,100	46,200	51,000	35,900	45,000	50,000	35,600	44,800	49,700	700	900	1,000
Women	200	300	600	100	300	500	100	300	500	([1])	([1])	([1])

[1]Less than 50.

[2]Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCES: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States* (biennial series, 1977-79) and unpublished data.

See figures 5-6, 5-12 and 5-18.

Appendix table 5-4. Doctoral scientists and engineers in the labor force by field, sex and employment status: 1973-79

Field and sex	Employed in S/E jobs			Employed in non-S/E jobs			Postdoctorates			Unemployed but seeking employment		
	1973	1977	1979	1973	1977	1979	1973	1977	1979	1973	1977	1979
All S/E fields	200,600	251,600	277,200	14,100	22,900	26,400	5,700	9,800	10,200	2,500	3,300	2,900
Men	185,900	228,600	249,400	12,700	20,400	23,000	4,800	7,700	8,000	1,800	2,300	2,000
Women	14,700	22,900	27,700	1,400	2,600	3,400	900	2,000	2,200	700	1,000	900
Physical scientists	42,400	48,800	52,200	4,200	6,000	5,800	1,900	2,600	2,200	900	800	700
Men	40,900	46,600	49,700	4,000	5,700	5,400	1,700	2,300	1,900	700	600	600
Women	1,500	2,200	2,500	300	400	400	100	300	300	100	200	100
Mathematical scientists	11,600	13,500	13,900	400	1,000	1,200	80	80	200	170	170	70
Men	10,900	12,500	12,900	400	900	1,100	75	70	200	150	140	([1])
Women	700	1,000	1,000	([1])	100	100	([1])	([1])	([1])	([1])	([1])	([1])
Computer specialists	2,700	5,600	6,600	([1])	100	100	([1])	([1])	([1])	([1])	([1])	([1])
Men	2,600	5,400	6,200	([1])	80	100	([1])	([1])	([1])	([1])	([1])	([1])
Women	100	200	400	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])
Environmental scientists[2]	9,900	12,200	13,800	250	500	500	180	400	300	100	100	50
Men	9,600	11,800	13,200	250	400	500	170	300	300	100	80	([1])
Women	200	400	600	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])
Life scientists	52,800	62,900	69,900	2,400	3,800	4,000	2,800	5,200	6,200	600	1,000	900
Men	47,700	55,800	60,900	2,000	3,200	3,300	2,200	3,900	4,700	300	700	500
Women	5,100	7,100	9,000	400	600	700	600	1,300	1,500	300	300	400
Social scientists	24,200	35,600	39,400	3,700	6,600	8,800	200	500	500	300	600	500
Men	21,700	30,700	33,700	3,300	5,700	7,300	200	400	300	200	400	300
Women	2,400	4,900	5,600	400	1,000	1,500	([1])	100	100	100	200	200
Psychologists	23,100	30,800	34,500	1,500	2,400	2,900	300	600	600	300	400	400
Men	18,700	23,900	26,300	1,200	1,800	2,100	200	400	400	100	200	300
Women	4,400	6,900	8,200	400	600	800	100	200	200	100	200	200
Engineers	33,900	42,100	46,900	1,600	2,600	3,100	200	400	300	300	300	300
Men	33,800	41,800	46,400	1,600	2,600	3,000	200	400	200	300	300	200
Women	100	300	500	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])

[1]Less than 50.
[2]Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCES: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States* (biennial series, 1977-79) and unpublished data.

See figures 5-15 and 5-18.

Appendix table 5-5. Doctoral scientists and engineers by field and employment status: 1979

Field	Total	In the labor force						Outside the labor force
			Employed					
		Labor force total	Total employed	Employed in S/E	Employed outside S/E	In post-doctoral appointments	Unemployed but seeking employment	
All S/E fields	332,300	316,700	313,800	277,200	26,400	10,200	2,900	15,600
Physical scientists	64,300	60,900	60,200	52,200	5,800	2,200	700	3,400
Chemists	42,700	40,100	39,600	34,600	3,600	1,400	500	2,600
Physicists and astronomers	21,700	20,800	20,600	17,600	2,200	900	200	800
Mathematical scientists	16,100	15,400	15,300	13,900	1,200	200	70	700
Mathematicians	13,600	13,100	13,000	11,600	1,200	200	70	600
Statisticians	2,400	2,400	2,400	2,300	100	([1])	([1])	50
Computer specialists	6,800	6,800	6,700	6,600	100	20	([1])	([1])
Environmental scientists	15,100	14,700	14,600	13,800	500	300	50	400
Earth scientists	11,600	11,100	11,100	10,500	500	100	([1])	400
Oceanographers	1,700	1,700	1,600	1,600	([1])	([1])	([1])	([1])
Atmospheric scientists	1,800	1,800	1,800	1,700	([1])	100	([1])	([1])
Engineers	51,600	50,600	50,300	46,900	3,100	300	300	1,100
Life scientists	86,300	81,000	80,100	69,900	4,000	6,200	900	5,400
Biological scientists	50,000	46,500	45,800	38,600	2,900	4,300	700	3,600
Agricultural scientists	16,100	15,200	15,100	14,100	700	200	100	900
Medical scientists	20,200	19,200	19,300	17,200	300	1,700	100	800
Psychologists	40,300	38,400	38,000	34,500	2,900	600	400	1,800
Social scientists	52,000	49,200	48,700	39,400	8,800	500	500	2,800
Economists	12,500	11,700	11,700	9,300	2,300	200	([1])	800
Sociologists and anthropologists	11,100	10,400	10,200	8,500	1,500	200	200	600
Other social scientists	28,400	27,000	26,700	21,600	5,000	70	300	1,400

[1]Less than 50.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See figure 5-1.

Appendix table 5-6. Reasons for nontechnical employment of experienced[1] scientists and engineers by field: 1978

(In percent)

Field	Total in non-S/E jobs	Prefer non-S/E jobs	Promoted out	Better pay	Locational preference	Believe S/E job not available	Other reasons	Reason not reported
All S/E's in nonscience and nonengineering jobs	100	16	37	9	6	7	20	5
Physical scientists	100	9	51	6	9	11	12	2
Mathematical scientists	100	9	32	13	4	7	30	5
Computer specialists	100	35	7	32	2	2	12	9
Environmental scientists[2]	100	21	8	21	([3])	16	27	7
Engineers	100	14	43	7	6	8	19	3
Life scientists	100	2	47	18	8	3	15	6
Psychologists	100	26	18	5	12	4	17	19
Social scientists	100	25	16	10	3	2	30	14

[1]Those who were in the labor force at the time of the 1970 Census of the Population.
[2]Includes earth scientists, oceanographers, and atmospheric scientists.
[3]Too few cases to estimate.

SOURCE: National Science Foundation, unpublished data.

See figure 5-2.

Appendix table 5-7. Percentage distribution of reasons for nontechnical employment of recent science and engineering graduates: 1979

	Total in non-S/E	Prefer non-S/E	Promoted out	Better pay	Locational preference	Believe S/E job not available	Other reasons
	1977 Bachelor's degree recipients						
All S/E fields	100.0	52.6	1.0	13.5	5.3	25.6	2.0
Physical sciences	100.0	67.7	1.8	11.3	3.3	10.6	5.3
Mathematical sciences	100.0	64.7	1.7	5.0	5.1	16.8	6.7
Computer sciences	100.0	40.2	(2)	19.5	(2)	11.0	29.3
Environmental sciences[1]	100.0	40.4	(2)	7.9	4.1	42.1	5.4
Life sciences	100.0	48.8	.9	8.7	4.9	34.1	2.5
Psychology	100.0	48.6	.8	19.5	3.1	27.3	.8
Social sciences	100.0	54.6	1.1	14.2	6.9	22.7	.4
Engineering	100.0	68.0	1.5	8.0	7.7	1.8	13.1
	1977 Master's degree recipients						
All S/E fields	100.0	65.7	1.9	7.9	7.5	13.6	3.4
Physical sciences	100.0	59.4	(2)	18.8	(2)	21.9	(2)
Mathematical sciences	100.0	96.3	(2)	(2)	(2)	3.7	(2)
Computer sciences	100.0	60.0	(2)	10.0	(2)	20.0	10.0
Environmental sciences[1]	100.0	88.9	(2)	4.2	(2)	6.9	(2)
Life sciences	100.0	72.2	(2)	4.5	9.3	14.1	(2)
Psychology	100.0	53.8	2.7	9.4	5.5	25.1	3.7
Social sciences	100.0	62.6	.8	11.4	11.6	9.8	3.8
Engineering	100.0	51.5	14.5	7.3	10.5	2.6	13.7

[1]Includes earth scientists, oceanographers, and atmospheric scientists.
[2]Too few cases to estimate.

SOURCE: National Science Foundation, unpublished data.

Science Indicators—1980

Appendix table 5-8. Average annual percent increases in employment in science and engineering and other economic variables: 1970-79

	1970-76	1976-79	1970-79
Scientists and engineers	3.0	2.5	2.8
Scientists	6.6	-1.1	4.0
Engineers	.4	5.4	2.1
Nonfarm wage and salary workers	1.9	4.1	2.6
Gross national product	2.9	4.0	3.2

SOURCES: National Science Foundation, unpublished data; and the *Economic Report of the President: 1980,* pp. 215 and 242.

See figure 5-3.

Science Indicators—1980

Appendix table 5-9. Employed scientists and engineers by field, sex, and primary work activity: 1974-78

Field	Total			Research			Development			Management of R&D		
	1974	1976	1978	1974	1976	1978	1974	1976	1978	1974	1976	1978
All S/E fields	2,248,200	2,377,200	2,473,200	210,400	231,700	278,000	380,500	396,400	407,300	191,300	202,600	228,200
Men	2,072,100	2,179,900	2,241,700	180,500	197,600	230,600	371,500	386,100	393,500	181,600	192,000	218,400
Women	176,100	197,200	231,500	29,800	34,100	47,300	9,000	10,100	13,800	9,700	10,500	9,800
Physical scientists	201,400	227,400	212,400	54,400	62,700	66,500	24,500	27,600	28,000	21,100	24,300	28,600
Men	185,500	207,500	197,400	48,900	55,400	59,700	22,900	25,900	26,400	20,800	23,700	28,000
Women	15,900	19,900	15,000	5,500	7,400	6,800	1,600	1,800	1,600	300	600	600
Mathematical scientists	82,800	88,300	88,400	4,800	5,500	12,700	6,200	6,700	3,600	5,400	5,800	6,800
Men	69,300	72,700	70,900	4,400	5,000	10,400	6,000	6,300	3,600	4,300	4,500	6,500
Women	13,500	15,600	17,500	400	500	2,300	200	400	(3)	100	1,300	300
Computer specialists	166,200	172,300	233,900	2,300	2,300	5,700	20,900	21,300	28,200	6,500	6,700	14,300
Men	134,900	138,700	193,400	1,900	2,000	5,300	17,300	17,500	23,700	5,800	5,900	13,200
Women	31,300	33,600	46,600	400	400	600	3,800	3,700	4,400	700	700	1,100
Environmental scientists[1]	69,100	74,800	72,300	14,900	15,900	20,600	2,700	2,800	5,500	3,100	3,600	4,500
Men	64,800	71,100	64,600	13,300	14,700	17,700	2,500	2,700	5,300	3,000	3,500	4,200
Women	4,300	3,700	7,700	1,500	1,300	2,800	200	100	200	100	100	300
Engineers	1,212,600	1,240,700	1,268,400	48,300	49,500	50,300	319,900	328,100	327,800	118,400	120,800	125,200
Men	1,208,300	1,234,000	1,248,500	47,900	48,800	48,300	318,200	325,900	323,700	118,100	120,500	123,800
Women	4,300	6,700	19,800	400	600	2,000	1,700	2,200	4,200	300	300	1,300
Life scientists	238,600	277,500	291,000	59,400	67,600	89,400	2,400	4,800	9,300	15,100	19,200	22,500
Men	193,400	226,100	227,800	43,400	49,500	63,900	2,000	4,200	6,800	12,600	15,500	19,300
Women	45,200	51,400	63,200	16,000	17,600	25,300	400	600	2,500	3,500	3,700	3,200
Psychologists	89,600	97,800	120,900	8,300	9,200	11,400	(3)	400	500	6,700	7,300	7,800
Men	71,500	76,700	89,700	6,300	6,800	8,200	(3)	300	300	6,000	6,400	6,200
Women	18,100	21,100	31,200	2,000	2,400	3,200	(3)	100	200	700	900	1,600
Social scientists	187,900	198,300	186,000	18,000	19,400	21,600	3,900	4,200	4,400	14,000	14,800	18,500
Men	144,400	153,200	149,500	14,400	15,400	17,200	2,600	3,400	3,700	11,000	11,800	17,200
Women	43,500	45,200	36,500	3,600	4,000	4,400	1,300	1,300	700	3,000	3,000	1,300

(continued)

Table 5-9. (Continued)

Field	Management			Teaching			Other activities[2]		
	1974	1976	1978	1974	1976	1978	1974	1976	1978
All S/E fields	353,500	370,800	394,800	223,700	237,100	225,200	888,900	938,700	940,000
Men	338,900	354,600	377,700	188,800	202,300	179,900	811,000	847,600	841,700
Women	14,600	16,300	17,100	34,800	34,800	45,200	78,000	91,300	98,300
Physical scientists	10,100	11,800	16,900	29,800	32,900	25,800	61,500	67,900	46,500
Men	9,700	11,300	16,300	27,900	31,000	24,400	55,300	60,200	42,600
Women	400	600	600	1,900	1,900	1,400	6,200	7,700	3,900
Mathematical scientists	6,000	6,600	8,600	25,000	28,200	29,300	35,400	35,500	27,600
Men	4,900	5,200	8,100	20,900	23,600	25,600	28,800	28,000	16,800
Women	1,100	1,300	500	4,100	4,700	3,700	6,600	7,500	10,800
Computer specialists	20,800	21,200	20,000	2,600	2,700	6,700	113,100	118,200	159,000
Men	17,800	18,100	18,500	2,200	2,300	5,600	89,900	92,900	127,100
Women	3,000	3,100	1,500	400	400	1,100	23,200	25,400	31,900
Environmental scientists[1]	9,000	9,800	7,100	6,500	6,500	6,300	33,000	36,200	28,400
Men	8,900	9,700	7,100	6,000	6,000	5,900	31,100	34,400	24,400
Women	100	200	(3)	400	300	400	2,000	1,800	3,900
Engineers	244,200	249,000	247,400	31,300	31,800	25,100	450,500	461,600	492,700
Men	243,800	248,500	246,800	31,300	31,800	25,000	449,000	458,700	481,100
Women	400	500	600	(3)	(3)	100	1,400	2,800	11,600
Life scientists	23,200	29,900	47,300	42,700	46,600	56,100	94,800	110,000	66,500
Men	21,100	27,200	42,300	32,700	37,000	37,500	81,700	92,800	57,900
Women	2,100	2,700	5,100	10,000	9,700	18,500	13,100	17,200	8,500
Psychologists	6,700	7,400	12,600	22,400	23,500	29,100	45,500	50,000	59,400
Men	5,200	5,800	9,800	18,300	19,400	17,600	35,700	38,000	47,600
Women	1,500	1,600	2,800	4,100	4,100	11,500	9,800	12,000	11,800
Social scientists	33,500	35,200	34,900	62,700	64,900	46,900	55,800	59,300	60,000
Men	27,500	28,900	28,800	49,500	51,300	38,300	39,500	42,200	44,300
Women	6,000	6,300	6,100	13,200	13,600	8,600	16,300	17,000	15,400

[1]Includes earth scientists, oceanographers, and atmospheric scientists.
[2]Includes consulting; production/inspection; reporting, statistical work, computing; other; and no report.
[3]Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCES: National Science Foundation, *U.S. Scientists and Engineers* (biennial series, 1976-78).

See figure 5-4.

Appendix table 5-10. Full-time-equivalent scientists and engineers employed in R&D by sector: 1954-80

(In thousands)

Year	Total	Federal Government[2]	Industry[3,4]	Universities and colleges	FFRDC's	Nonprofit organizations[3]
1954	237.1	37.7	164.1	25.0	5.0	5.3
1961	425.7	51.1	312.0	42.4	9.1	11.1
1965	494.5	61.8	348.4	53.4	11.1	19.9
1969	555.2	68.5	385.6	68.3	11.6	21.2
1972	518.3	64.4	353.9	66.5	11.7	21.8
1973	518.4	61.8	358.8	63.5	12.0	22.3
1974	525.1	62.6	361.6	65.5	12.1	23.3
1975	534.9	63.4	363.8	70.2	12.7	24.8
1976	549.2	64.0	373.6	71.8	13.4	26.4
1977	573.9	64.7	393.2	74.5	14.0	27.5
1978	601.6	65.4	415.8	77.7	14.7	28.0
1979[1]	629.5	66.0	440.0	80.0	15.0	28.5
1980[1]	659.0	66.5	465.0	82.5	16.0	29.0

[1]Estimates.
[2]Includes both civilian and military service personnel and managers of R&D.
[3]Includes professional R&D personnel employed at federally funded research and development centers administered by organizations in this sector.
[4]Excludes social scientists.

SOURCES: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), p. 33.

Science Indicators—1980

Appendix table 5-11. Employed doctoral scientists and engineers by primary work activity: 1973-79

Primary work activity	1973		1977		1979	
	Number	Percent	Number	Percent	Number	Percent
Total	220,400	100	284,200	100	313,800	100
Research and development	97,700	44	124,200	44	142,700	45
Basic research	34,300	16	43,500	15	47,900	15
Applied research	28,700	13	36,400	13	36,800	12
Development	8,500	4	13,500	5	15,000	5
Management of R&D	26,200	12	30,700	11	43,000	14
Teaching	80,000	36	90,400	32	91,900	29
Management and administration[1]	19,900	9	29,700	10	29,200	9
Consulting	4,100	2	6,100	2	9,000	3
Sales and professional services	8,100	4	15,200	5	21,000	7
Other activities	7,000	3	12,800	5	15,800	5
Activity not reported	3,700	2	5,800	2	4,200	1

[1]Other than R&D.

NOTE: Detail may not add to totals because of rounding.

SOURCES: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States* (biennial series, 1977-1979).

Science Indicators—1980

Appendix table 5-12. Trends in Graduate Record Examination mean verbal and quantitative test scores by field: 1970/71 and 1977/78

Prospective field of graduate study	Aptitude type	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76	1976/77	1977/78
					Science fields				
Physical sciences	V	512	500	519	502	508	500	514	517
	Q	650	643	648	648	630	623	634	636
Mathematical sciences	V	517	495	510	513	506	520	513	504
	Q	675	673	676	675	661	673	666	669
Engineering	V	444	448	455	449	440	471	462	459
	Q	656	651	665	663	649	654	657	657
Life sciences	V	491	491	504	508	508	506	506	503
	Q	556	553	570	569	568	557	558	559
Basic social sciences	V	533	527	522	525	521	534	526	516
	Q	530	526	521	521	518	526	518	514
					Nonscience fields				
Health professions	V	500	502	509	508	502	513	507	498
	Q	496	501	508	507	513	530	527	517
Education	V	472	463	452	449	454	464	454	446
	Q	462	457	450	442	445	459	449	449
Arts and humanities	V	546	534	537	541	542	537	543	532
	Q	494	492	493	494	490	494	502	497
Applied social sciences	V	492	482	484	493	488	471	477	483
	Q	480	475	475	477	464	461	465	472
Other nonscience	V	496	490	501	498	496	507	498	486
	Q	498	500	502	495	498	509	510	504

NOTE: V = verbal, Q = quantitative. Standard deviations cannot be computed for all years. For 1976/77, however, standard deviations ranged between 100 and 138.

SOURCES: Data for the years 1970/71 through 1974/75 are from a one-in-fifteen sample study of examinees of those years. See Robert F. Boldt, *Trends in Aptitude of Graduate Students in Science* (Princeton, N.J.: Educational Testing Service), p. 20. Mean scores for 1975/76 and 1967/77 were calculated from unpublished tabulations furnished by the Educational Testing Service, based on the test results of a high proportion of all examinees of those years. Mean scores for 1977/78 are from *A Summary of Data Collected from Graduate Record Examination Test Takers During 1977/78, Data Summary Report #3* (Princeton, N.J.: Educational Testing Service), February 1978, Tables 13, 14 and 42; pp. 42, 81-84 and 85-88.

See figure 5-5.

Science Indicators—1980

Appendix table 5-13. Employed scientists and engineers by field, sex, and type of employer: 1974-78

Field	Total			Business and industry			Educational institutions			Federal Government			All other employers[1]		
	1974	1976	1978	1974	1976	1978	1974	1976	1978	1974	1976	1978	1974	1976	1978
All S/E fields	2,248,200	2,377,200	2,473,200	1,376,200	1,433,100	1,528,100	341,300	370,700	380,800	189,100	205,600	205,800	341,500	367,800	358,400
Men	2,072,100	2,179,900	2,241,700	1,313,800	1,362,600	1,445,300	288,200	312,100	304,800	175,500	189,700	187,300	294,500	315,600	304,600
Women	176,100	197,200	231,500	62,400	70,500	82,700	53,100	58,600	76,000	13,600	15,900	18,600	47,000	2,200	54,000
Physical scientists	201,400	227,400	212,400	98,000	108,700	116,300	47,400	54,100	55,500	19,600	22,800	18,000	36,400	41,700	22,600
Men	185,500	207,500	197,400	89,300	99,000	108,400	44,200	49,400	51,500	18,800	21,100	16,900	33,200	38,000	20,500
Women	15,900	19,900	15,000	8,700	9,700	7,900	3,200	4,700	4,000	800	1,800	1,100	3,200	3,900	2,100
Mathematical scientists	82,800	88,300	88,400	32,000	33,600	34,200	31,900	34,600	35,100	7,900	8,700	9,400	11,000	11,300	9,700
Men	69,300	72,700	70,900	27,000	27,900	25,600	28,100	29,800	28,600	6,100	6,600	8,800	8,100	8,400	7,800
Women	13,500	15,600	17,500	5,000	5,700	8,600	3,800	4,800	6,500	1,800	2,100	600	2,900	3,000	1,800
Computer specialists	166,200	172,300	233,900	121,600	125,900	173,000	13,400	13,800	17,900	13,900	14,300	14,600	17,300	18,200	28,800
Men	134,900	138,700	193,400	99,100	101,600	145,100	10,600	10,900	13,900	11,300	11,600	12,300	13,900	14,600	22,300
Women	31,300	33,600	40,600	22,500	24,300	27,800	2,800	2,900	4,000	2,600	2,800	2,300	3,400	3,800	6,600
Environmental scientists[2]	69,100	74,800	72,300	36,200	40,400	40,400	10,100	11,100	12,900	10,600	11,100	10,400	12,100	12,200	8,600
Men	64,800	71,100	64,600	34,800	38,900	36,000	9,100	10,500	11,300	9,600	10,500	9,500	11,200	11,200	7,900
Women	4,300	3,700	7,700	1,400	1,500	4,400	1,000	600	1,600	1,000	600	900	900	900	700
Engineers	1,212,600	1,240,700	1,268,400	939,600	959,700	985,400	43,100	43,900	48,700	95,100	97,500	90,600	134,800	139,500	143,700
Men	1,208,300	1,234,000	1,248,500	936,700	955,100	969,100	42,900	43,600	47,700	94,700	96,900	89,200	134,000	138,400	142,500
Women	4,300	6,700	19,800	2,900	4,600	16,300	200	300	900	400	700	1,400	800	1,100	1,200
Life scientists	238,600	277,500	291,000	89,500	102,000	86,400	75,300	86,100	94,400	17,900	25,600	41,800	55,900	63,700	68,200
Men	193,400	226,000	227,800	78,000	88,300	77,300	56,300	65,500	65,500	16,000	23,100	35,500	43,100	49,000	49,600
Women	45,200	51,400	63,200	11,500	13,700	9,100	19,000	20,700	28,900	1,900	2,500	6,400	12,800	14,600	18,800
Psychologists	89,600	97,800	120,900	17,700	18,700	31,600	39,300	42,900	55,300	5,100	5,400	4,000	27,500	30,700	29,900
Men	71,500	76,700	89,700	14,100	14,800	28,500	33,700	36,100	36,000	4,500	4,700	3,100	19,200	21,200	22,100
Women	18,100	21,100	31,200	3,600	3,900	3,000	5,600	6,700	19,400	600	700	900	8,300	9,600	7,900
Social scientists	187,900	198,300	186,000	41,600	44,100	60,800	80,800	84,300	61,300	19,000	20,000	17,000	46,500	49,900	46,700
Men	144,500	153,200	149,500	34,800	37,000	55,300	63,300	66,300	50,200	14,500	15,300	12,000	31,800	34,600	31,900
Women	43,400	45,200	36,500	6,800	7,100	5,600	17,500	17,900	11,100	4,500	4,700	5,000	14,700	15,400	14,900

[1]Includes nonprofit organizations, military, State, local, and other government, other and no report.
[2]Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCES: National Science Foundation, *U.S. Scientists and Engineers* (biennial series, 1976-78).

See figure 5-7 and 5-10.

Appendix table 5-14. Employed doctoral scientists and engineers by type of employer and Federal support status: 1973-79

	1973		1977		1979	
	Number	Percent	Number	Percent	Number	Percent
Total employed	220,400	100	284,200	100	313,800	100
Type of employer:						
Educational institutions	129,400	59	163,100	57	174,000	55
Business and industry	53,400	24	71,500	25	82,900	26
Federal Government[1]	20,200	9	23,600	8	26,200	8
Nonprofit organizations	8,000	4	10,200	4	12,500	4
Hospitals and clinics	4,500	2	8,600	3	9,700	3
Other employers	4,600	2	5,800	2	7,000	2
Employer not reported	300	([2])	1,400	([2])	1,400	([2])
Federal support status:						
Receiving Federal support	103,400	47	119,600	42	126,500	40
No Federal support	108,300	49	152,700	54	170,700	54
Support status unknown	4,900	2	7,500	3	9,200	3
Support status not reported	3,800	1	4,500	2	7,300	2

[1]Includes the military services and the Commissioned Corps.
[2]Less than 0.5 percent.

NOTE: Detail may not add to totals because of rounding

SOURCES: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States* (biennial series, 1973-79) and "Work Activities of Doctoral Scientists and Engineers Show Substantial Change Between 1973 and 1977," *Science Resources Studies Highlights* (NSF 78-316).

See figure 5-7.

Science Indicators—1980

Appendix table 5-15. Employed scientists and engineers as an average percent of total nonproduction workers in selected industries: 1953-77

Industry	Average percents for each period			
	1953-1957	1958-1962	1963-1967	1968-1977
Chemicals	24	25	24	22
Primary metals	10	12	12	11
Fabricated metals	9	10	10	10
Electrical machinery	13	15	15	14
Electrical equipment	24	26	27	24
Instruments	19	22	23	19

SOURCE: National Science Foundation, unpublished data.

See figure 5-8.

Science Indicators—1980

Appendix table 5-16. Concentration ratios[1] of employed scientists and engineers for selected industries: 1978

Industry	Scientists and engineers	Scientists	Engineers
Total nonmanufacturing	1.00	1.00	1.00
Mining	2.77	3.41	2.39
Metal	2.82	3.77	2.28
Coal	1.01	.45	1.34
Crude, petroleum and natural gas	4.33	5.82	3.45
Nonmetal mining	.87	.81	.91
Total manufacturing	1.00	1.00	1.00
Durable goods	1.30	.70	1.40
Primary metals	.60	.60	.70
Fabricated metals	.60	.40	.70
Machinery	1.50	.70	1.70
Electrical equipment	2.30	.90	2.60
Instruments	2.00	1.20	2.10
Nondurable goods	.60	1.50	.40
Chemicals	2.50	7.50	1.30
Petroleum refining	2.60	5.10	2.00
Rubber and plastics	.50	.50	.50

[1]A concentration ratio relates each industry's share of science and engineering employment to its share of total (i.e., S/E and non-S/E) employment. That is: $C_i = (S_i/S)/(E_i/E)$, where C is the concentration ratio for industry i, S_i is the number of scientists and engineers in industry i, S is the total number of scientists and engineers in the sector (manufacturing), E_i is the total employment in industry i, and E is the total employment in the sector.

SOURCE: National Science Foundation, unpublished data.

Science Indicators—1980

Appendix table 5-17. Relationship of science/engineering concentration to total employment growth: 1965-79.

Industry	SIC[1]	Concentration ratios, total S/E (1978)	Total employment (in thousands) 1965	1977	1979	Percent change 1965-79	1977-79
Above-average concentration		2.0	6,614.8	7,713.7	8,636.4	30.6	12.0
Petroleum refining	29	2.6	182.9	209.4	213.8	16.9	2.1
Chemicals	28	2.5	907.8	1,057.6	1,112.7	22.6	5.2
Electrical equipment	36	2.3	1,659.2	1,935.5	2,108.7	27.1	8.9
Transportation equipment	37	2.0	1,740.6	1,797.0	2,048.3	17.7	14.0
Professional & scientific instruments	38	2.0	389.0	527.2	690.4	77.5	31.0
Machinery	35	1.5	1,735.3	2,187.0	2,462.5	41.9	12.6
Below-average concentration		.3	11,220.9	11,686.9	12,335.8	9.9	5.6
Primary metals	33	.6	1,301.0	1,204.1	1,243.9	−4.4	3.3
Tobacco	21	.7	86.8	69.8	66.2	−23.7	−5.2
Fabricated metals	34	.6	1,269.0	1,451.6	1,727.2	36.1	19.0
Rubber & plastics	30	.5	470.8	675.9	767.5	63.0	13.6
Paper	26	.4	639.1	698.9	714.1	11.7	2.2
Stone, clay & glass	32	.4	628.3	652.2	710.8	13.1	9.0
Miscellaneous manufacturing	39	.3	419.5	418.5	452.4	7.8	8.1
Textiles	22	.2	925.6	981.9	891.9	−3.6	−9.2
Food & kindred products	20	.2	1,756.7	1,719.9	1,716.3	−2.3	−.2
Furniture	25	.2	430.7	507.9	487.3	13.1	−4.1
Lumber & wood	24	.1	606.9	642.3	358.4	25.0	18.1
Printing & publishing	27	.1	979.4	1,109.4	1,242.9	26.9	12.0
Leather	31	.1	352.9	264.3	243.8	−30.9	−7.8
Apparel	23	.1	1,354.2	1,288.7	1,313.1	−3.0	1.9

[1]Standard Industrial Classification.

SOURCES: National Science Foundation, "Manufacturing Industries with High Concentrations of Scientists and Engineers Lead in 1965-77 Employment Growth," *Science Resources Studies Highlights* (NSF 79-307) and Bureau of Labor Statistics, *Employment and Earnings* (March 1980).

See figure 5-9.

Appendix table 5-18. Scientists and engineers employed in science and engineering jobs by field and type of employer: 1978

Field	Total	Business and industry	Educational institutions	Nonprofit organizations	Federal Government	State and local government	Other government	Military	Other and no report
All S/E fields	2,091,900	1,382,500	326,400	55,300	163,700	88,100	45,700	14,900	15,300
Physical scientists	184,700	102,300	52,600	7,000	14,000	3,600	3,400	500	1,300
Chemists	125,700	80,500	28,000	3,600	7,200	2,900	1,900	300	1,200
Physicists and astronomers	44,000	15,400	20,900	2,200	4,700	200	500	([1])	100
Other physical scientists	15,000	6,400	3,700	1,200	2,100	500	1,000	100	([1])
Mathematical scientists	42,900	14,700	22,100	1,500	3,100	900	400	200	([1])
Mathematicians	38,300	13,500	19,300	1,500	2,800	700	400	100	([1])
Statisticians	4,600	1,200	2,800	([1])	300	200	([1])	100	([1])
Computer specialists	231,400	171,500	16,700	11,000	14,600	6,800	3,700	2,900	4,300
Environmental scientists	62,400	33,300	12,200	1,000	10,300	4,100	1,300	100	100
Earth scientists	53,200	31,000	10,300	300	7,000	3,900	700	([1])	([1])
Oceanographers	1,400	200	500	([1])	500	100	100	([1])	100
Atmospheric scientists	7,800	2,100	1,400	700	2,800	100	600	100	100
Engineers	1,201,200	951,700	46,800	17,400	84,700	49,100	32,000	10,800	8,700
Aeronautical and astronautical	42,800	28,000	1,200	1,200	9,400	200	600	2,000	200
Chemical	57,800	51,200	2,600	600	1,700	300	300	100	1,000
Civil	161,600	92,700	4,600	1,300	18,700	30,200	12,000	1,200	900
Electrical and electronic	222,600	177,600	8,800	4,400	24,000	1,200	4,100	2,000	500
Mechanical	218,200	189,100	11,000	1,500	11,300	600	2,600	900	1,200
Other engineers	498,200	413,100	18,600	8,400	19,600	16,600	12,400	4,600	4,900
Life scientists	201,800	57,600	86,100	13,000	29,500	12,800	1,900	100	800
Biological scientists	74,100	11,900	49,200	2,900	5,300	4,300	500	([1])	([1])
Agricultural scientists	85,400	40,900	11,600	3,200	22,500	6,500	700	([1])	([1])
Medical scientists	42,300	4,600	25,300	6,900	1,900	2,000	700	100	800
Psychologists	71,200	21,400	42,700	3,100	1,600	1,600	500	300	([1])
Social scientists	96,200	30,100	47,200	1,300	5,700	9,200	2,500	([1])	200
Economists	34,300	15,500	13,200	800	2,800	600	1,400	([1])	([1])
Sociologists and anthropologists	9,400	1,500	6,600	300	500	400	([1])	([1])	100
Other social scientists	52,500	13,100	27,400	200	2,400	8,200	1,100	([1])	100

[1]Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See figure 5-10.

Appendix table 5-19. Scientists and engineers employed in science and engineering jobs by field and primary work activity: 1978

Field	Total	Research and development: R&D Total	Research and development: Basic research	Research and development: Applied research	Research and development: Development	Research and development: R&D management	Other management	Teaching	Consulting	Production and inspection	Reports, statistical work and computing	Other activities and no report
All S/E fields	2,091,900	855,500	107,300	127,000	397,600	223,600	298,700	201,300	110,600	321,400	259,600	44,800
Physical scientists	184,700	119,500	32,500	33,000	27,000	27,000	5,800	25,100	3,900	23,300	7,200	(1)
Chemists	125,700	81,600	19,200	22,500	21,200	18,700	4,700	13,400	2,300	20,700	3,100	(1)
Physicists and astronomers	44,000	28,800	11,000	7,300	3,600	6,900	900	9,700	600	1,100	2,900	(1)
Other physical scientists	15,000	9,100	2,300	3,200	2,200	1,400	200	2,000	1,000	1,500	1,200	(1)
Mathematical scientists	42,900	15,700	6,800	1,900	2,500	4,500	900	18,400	1,200	100	6,600	(1)
Mathematicians	38,300	15,000	6,700	1,800	2,400	4,100	800	15,700	1,100	100	5,600	(1)
Statisticians	4,600	700	100	100	100	400	100	2,700	100	(1)	1,000	(1)
Computer specialists	231,400	48,200	1,000	4,700	28,200	14,300	20,000	6,700	11,500	9,200	128,400	7,400
Environmental scientists	62,400	30,600	7,500	13,100	5,500	4,500	5,900	6,200	3,800	4,800	10,400	700
Earth scientists	53,200	26,300	6,400	11,500	4,900	3,500	5,100	5,400	3,400	3,700	9,300	(1)
Oceanographers	1,400	1,100	600	200	100	200	100	100	(1)	100	(1)	(1)
Atmospheric scientists	7,800	3,200	500	1,400	500	800	700	700	400	1,000	1,100	700
Engineers	1,201,200	503,200	8,500	41,800	327,800	125,100	229,500	22,700	65,500	256,500	88,900	34,900
Aeronautical and astronautical	42,800	26,300	900	3,500	14,800	7,100	3,500	900	1,300	5,000	5,000	900
Chemical	57,800	33,200	1,100	3,500	23,000	5,600	6,500	2,000	2,300	13,200	500	(1)
Civil	161,600	36,600	1,000	2,300	26,400	6,900	51,200	2,800	21,800	33,100	10,800	5,200
Electrical and electronic	222,600	128,200	1,300	9,500	96,300	21,100	15,700	5,000	9,000	41,600	17,400	5,700
Mechanical	218,200	117,600	1,000	6,800	91,300	18,500	28,800	5,000	9,700	40,100	9,400	7,500
Other engineers	498,200	161,100	3,200	16,100	75,900	65,900	123,800	7,100	21,400	123,500	45,800	15,500
Life scientists	201,800	81,200	35,200	20,000	3,500	22,500	33,900	53,200	6,300	18,600	6,800	1,800
Biological scientists	74,100	36,700	23,800	(1)	800	12,100	(1)	33,400	700	3,100	200	(1)
Agricultural scientists	85,400	27,600	4,000	16,000	200	7,400	28,400	5,100	3,900	14,600	5,800	(1)
Medical scientists	42,300	16,900	7,400	4,000	2,500	3,000	5,500	14,700	1,700	900	800	1,800
Psychologists	71,200	17,900	4,000	5,800	300	7,800	100	29,100	13,700	5,100	5,300	(1)
Social scientists	96,200	39,200	11,800	6,700	2,800	17,900	2,600	39,900	4,700	3,800	6,000	(1)
Economists	34,300	14,100	3,400	3,500	800	6,400	2,600	10,800	2,200	1,500	3,100	(1)
Sociologists and anthropologists	9,400	4,000	2,100	100	(1)	1,800	(1)	5,000	200	(1)	200	(1)
Other social scientists	52,500	21,100	6,300	3,100	2,000	9,700	(1)	24,100	2,300	2,300	2,700	(1)

[1]Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

Appendix table 5-20. Scientists and engineers employed in science and engineering jobs by sector and primary work activity: 1978

	Total	Research and development[1]	Management of R&D	Other management	Teaching	Production/ inspection	Reporting, stat. work and comp.	Other activities[2]
Total	2,091,900	631,900	223,600	298,700	201,300	321,400	259,600	155,400
Business/industry	1,382,500	450,700	152,300	202,000	5,100	261,300	184,500	126,600
Scientists	430,800	133,700	56,900	32,900	4,600	45,800	120,100	36,800
Engineers	951,700	317,000	95,400	169,100	500	215,500	64,400	89,800
Educational institutions	326,400	77,100	19,200	11,300	193,800	2,400	14,300	8,300
Scientists	279,600	69,700	14,400	6,100	171,600	1,000	10,400	6,400
Engineers	46,800	7,400	4,800	5,200	22,200	1,400	3,900	1,900
Nonprofit organizations	55,300	20,800	8,000	6,700	500	2,600	10,000	6,700
Scientists	37,900	14,300	3,600	4,400	500	1,200	8,800	5,100
Engineers	17,400	6,500	4,400	2,300	(3)	1,400	1,200	1,600
Federal Government	163,700	45,900	26,400	39,500	600	24,100	22,900	4,300
Scientists	79,000	22,800	11,500	18.700	600	10,000	13,700	1,700
Engineers	84,700	23,100	14,900	20,800	(3)	14,100	9,200	2,600
State and local government	88,100	15,200	10,600	24,200	700	17,200	16,000	4,200
Scientists	39,000	7,500	9,100	5,200	700	4,900	9,700	1,900
Engineers	49,100	7,700	1,500	19,000	(3)	12,300	6,300	2,300
Other[4]	75,900	22,200	7,100	15,000	600	13,800	11,900	5,200
Scientists	24,400	5,800	3,000	1,900	600	2,000	8,000	3,000
Engineers	51,500	16,400	4,100	13,100	(3)	11,800	3,900	2,200

[1]Excluding management of R&D.
[2]Includes consulting, other, and no report.
[3]Too few cases to estimate.
[4]Includes military, other govenment, other, and no report.

SOURCE: National Science Foundation, unpublished data.

See figure 5-11.

Appendix table 5-21. Doctoral scientists and engineers by type of employer and age: 1979

Type of employer	Total	Age								
		Under 30	30-34	35-39	40-44	45-49	50-54	55-59	60-64	Over 64[1]
Total	332,300	8,000	54,700	77,400	55,100	40,700	33,900	27,500	17,800	17,200
Business and industry	82,800	1,800	14,300	21,600	14,900	10,100	7,700	6,600	3,700	2,200
Educational institutions	174,000	4,500	28,400	39,800	29,300	23,400	19,400	15,500	9,200	4,400
4-year colleges & universities	167,000	4,400	27,700	38,200	28,000	22,500	18,400	14,800	8,800	4,200
Other edducational institutions	7,000	100	700	1,600	1,300	900	1,000	700	400	200
Hospitals and clinics	9,700	500	2,500	2,200	1,200	900	1,000	800	400	200
Nonprofit organizations	12,500	300	2,300	3,400	2,100	1,100	1,300	1,000	600	500
Government	32,300	400	5,000	8,500	6,400	4,200	3,400	2,400	1,300	800
Federal[2]	26,200	300	3,700	7,100	5,400	3,300	2,900	2,000	1,000	600
State	4,200	100	900	900	800	500	400	300	200	100
Other	1,900	(3)	400	500	200	400	100	100	100	100
Other employers	900	50	100	200	200	100	200	(3)	(3)	(3)
No report	1,400	(3)	100	200	200	200	100	100	200	400
Not employed	18,500	400	2,000	1,500	800	900	800	1,000	2,400	8,800

[1]Includes those who did not report their age.
[2]Includes the military services and the Commissioned Corps.
[3]Less than 50.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

Appendix table 5-22. Doctoral scientists and engineers by primary work activity and age: 1979

Primary work activity	Total	Age								
		Under 30	30-34	35-39	40-44	45-49	50-54	55-59	60-64	Over 64[1]
Total	332,300	7,900	54,700	77,400	55,100	40,700	33,900	27,500	17,800	17,200
Research and development:										
Basic research	47,900	2,700	13,000	12,300	7,100	4,300	3,700	2,500	1,500	800
Applied research	36,800	1,400	8,200	9,700	5,900	4,100	3,300	2,700	1,200	500
Development	15,000	300	3,000	4,300	3,000	1,600	1,000	1,100	500	300
Management of R&D	43,000	300	5,600	10,100	8,600	5,900	5,500	3,800	2,400	800
Management and administration	29,200	60	2,100	6,100	5,200	5,300	4,100	3,500	2,000	700
Teaching	91,900	1,600	12,400	21,500	16,700	12,600	10,700	9,000	5,100	2,500
Report writing	5,500	100	900	1,300	900	600	400	500	300	400
Consulting	9,000	200	1,200	2,500	1,400	1,100	900	600	500	800
Production & inspection	4,100	80	500	1,100	700	600	400	400	200	100
Sales & professional services	21,000	700	4,300	5,100	3,100	2,300	2,100	1,700	900	800
Other activities	6,100	100	1,100	1,300	1,200	700	700	500	400	200
No report	4,200	([2])	500	800	500	600	500	300	400	600
Not employed	18,500	400	2,000	1,500	800	900	800	1,000	2,400	8,800

[1]Includes those who did not report their age.
[2]Less than 50.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

Appendix table 5-23. Doctoral scientists and engineers in educational institutions by field and primary work activity: 1973-79

Field	Total			Research and development[1]			Management of R&D			Other management		
	1973	1977	1979	1973	1977	1979	1973	1977	1979	1973	1977	1979
All S/E fields	129,400	163,100	174,000	30,700	42,600	46,800	4,500	6,100	8,300	9,100	13,900	18,200
Physical scientists	22,000	27,100	27,200	5,600	8,800	8,800	700	1,100	1,600	1,100	1,800	2,100
Mathematical scientists	10,500	12,200	12,600	1,600	2,000	2,200	90	60	200	500	900	1,100
Computer specialists	1,400	2,100	2,500	300	500	600	60	100	200	200	300	400
Environmental scientists[3]	5,200	6,300	6,200	1,400	1,800	2,000	300	400	600	300	400	500
Engineers	13,000	15,900	17,000	2,200	3,500	4,000	700	1,200	1,300	1,100	2,000	2,400
Life scientists	39,200	47,500	52,200	15,200	19,400	22,300	1,700	2,100	2,800	2,400	3,300	4,800
Psychologists	15,100	18,600	19,900	2,100	2,500	3,200	500	500	500	1,600	1,900	2,700
Social scientists	23,000	33,400	36,300	2,400	4,100	3,800	400	700	1,000	2,100	3,300	4,400

(continued)

Table 5-23. (Continued)

Field	Teaching			Consulting			Sales and professional services			Other activities		
	1973	1977	1979	1973	1977	1979	1973	1977	1979	1973	1977	1979
All S/E fields	78,900	89,300	90,900	500	1,000	900	1,700	3,300	3,800	3,900	6,900	5,100
Physical scientists	14,100	14,600	14,300	([2])	([2])	90	([2])	90	50	400	700	400
Mathematical scientists	8,000	9,000	8,800	([2])	([2])	([2])	([2])	([2])	([2])	200	200	200
Computer specialists	900	1,200	1,100	([2])	([2])	50	([2])	([2])	([2])	([2])	90	80
Environmental scientists[3]	3,100	3,500	2,900	([2])	([2])	([2])	([2])	([2])	([2])	200	100	100
Engineers	8,700	8,700	9,200	([2])	50	([2])	([2])	40	([2])	300	400	300
Life scientists	17,900	18,700	19,000	200	300	400	300	1,100	1,300	1,500	2,400	1,800
Psychologists	9,000	10,500	10,300	200	300	300	1,200	1,900	2,300	400	900	600
Social scientists	17,200	23,100	25,300	600	200	90	50	100	100	900	1,900	1,500

[1]Excluding management of R&D.
[2]Too few cases to estimate.
[3]Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals.

SOURCES: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States* (biennial series, 1977-79).

See Figures 5-15, 5-13 and 5-15.

Appendix table 5-24. Doctoral scientists and engineers in educational institutions by age and field: 1973 and 1979

Field	Total		Age: Under 30		30-34		35-39		40-44		45-49		50-54		55-59		60-64		Over 64	
	1973	1979	1973	1979	1973	1979	1973	1979	1973	1979	1973	1979	1973	1979	1973	1979	1973	1979	1973	1979
All S/E fields	129,400	174,000	5,900	4,500	29,000	28,400	24,900	39,800	20,800	29,300	17,500	23,400	13,700	19,400	9,000	15,500	5,500	9,200	3,100	4,300
Physical scientists	22,000	27,200	1,300	600	5,800	4,100	4,600	6,000	3,500	5,400	2,400	3,600	1,800	3,000	1,300	2,200	800	1,700	600	700
Mathematical scientists	10,500	12,600	800	400	3,100	1,900	2,200	3,500	1,500	2,400	1,100	1,700	700	1,000	500	700	400	600	200	300
Computer specialists	1,400	2,500	80	100	400	500	200	800	300	300	100	300	100	200	60	100	([1])	100	([1])	([1])
Environmental scientists[2]	5,100	6,200	200	200	1,000	900	1,100	1,500	1,000	1,000	600	1,200	600	600	300	500	200	200	200	100
Engineers	13,000	17,000	400	400	2,700	2,200	3,100	3,200	2,200	3,500	1,800	2,900	1,600	2,200	600	1,900	400	700	200	100
Life scientists	39,200	52,200	1,500	1,300	8,700	10,300	6,600	11,700	6,100	7,900	5,800	6,500	4,100	5,900	3,000	4,400	1,900	2,900	1,000	1,300
Psychologists	15,100	19,900	900	900	3,200	3,700	2,800	4,400	2,400	3,000	2,300	2,400	1,700	2,500	1,000	1,800	600	900	300	500
Social scientists	23,000	36,300	800	600	4,100	4,900	4,200	8,800	3,800	5,900	3,300	4,700	3,100	4,200	2,000	3,900	1,200	2,100	500	1,300

[1]Less than 50.
[2]Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCES: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States* (biennial series, 1973-1979).

See figure 5-14.

Appendix table 5-25. Annual unemployment rates: 1963-79

(In percent)

Year	Total labor force	Professional and technical workers	Scientists		Engineers	
			Total	Doctoral	Total	Doctoral
1963	5.7	1.8	NA	NA	1.2	NA
1964	5.2	1.7	NA	NA	1.5	NA
1965	4.5	1.5	NA	NA	1.1	NA
1966	3.8	1.3	.4	NA	.7	NA
1967	3.8	1.3	NA	NA	.6	NA
1968	3.6	1.2	.9	.5	.7	NA
1969	3.5	1.3	NA	NA	.8	NA
1970	4.9	2.0	1.6	.9	2.2	NA
1971	5.9	2.9	2.6	1.4	2.9	1.9
1972	5.6	2.4	NA	NA	2.0	NA
1973	4.9	2.2	NA	1.2	1.0	.8
1974	5.6	2.3	2.2	NA	1.3	NA
1975	8.5	3.2	NA	1.0	2.6	.7
1976	7.7	3.2	4.0	NA	2.0	NA
1977	7.0	3.0	NA	1.3	1.3	.6
1978	6.0	2.6	1.5	NA	1.3	NA
1979	5.8	2.4	1.6	1.0	1.4	.5

SOURCES: *Economic Report of the President, 1980,* p. 237; U.S. Department of Labor, Bureau of Labor Statistics, *Employment and Earnings,* January 1980, Vol. 27, no. 1, p. 167; National Science Foundation, *American Science Manpower* (biennial series, 1964-70); National Science Foundation, *Unemployment Rates and Unemployment Characteristics for Scientists and Engineers, 1971* (NSF 72-307), p. 11; National Science Foundation, *U.S. Scientists and Engineers* (biennial series 1976-78); National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States* (biennial series 1977-79); and National Science Foundation, unpublished data.

Science Indicators—1980

Appendix table 5-26. Annual unemployment rates for engineers as percent of the rates for professional and technical workers: 1967-79

Year	Unemployment rates (Percent)		Engineers' unemployment rate as a percent of the unemployment rate for professional and technical workers
	Engineers	Professional and technical workers	
1967	0.6	1.3	46
1968	.7	1.2	58
1969	.8	1.3	62
1970	2.2	2.0	110
1971	2.9	2.9	100
1972	2.0	2.4	83
1973	1.0	2.2	45
1974	1.3	2.3	57
1975	2.6	3.2	81
1976	2.0	3.2	63
1977	1.3	3.0	43
1978	1.3	2.6	50
1979	1.4	2.4	58

SOURCES: U.S. Department of Labor, Bureau of Labor Statistics, *Employment and Earnings* January 1980, vol. 27, no. 1, p. 167; National Science Foundation, *U.S. Scientists and Engineers* (biennial series, 1976-78); National Science Foundation and Bureau of Labor Statistics, unpublished data.

Science Indicators—1980

Appendix table 5-27. S/E utilization rates by field, sex and degree: 1978 and 1979

Field	All scientists and engineers (1978)			Doctoral scientists and engineers (1979)		
	Total	Men	Women	Total	Men	Women
All S/E fields	83.4	86.2	56.7	90.7	91.2	87.3
Physical scientists	85.2	86.9	64.4	89.4	89.6	85.6
Chemists	85.7	87.8	65.4	89.9	90.1	86.0
Physicists and astronomers	84.1	84.6	64.9	88.5	88.6	84.0
Other physical scientists	84.4	86.9	54.1	—	—	—
Mathematical scientists	47.8	53.1	26.4	91.9	92.0	90.5
Mathematicians	46.8	52.8	23.6	90.6	90.7	89.2
Statisticians	57.0	56.6	58.7	98.7	98.7	98.8
Computer specialists	98.7	98.5	99.2	98.2	98.2	98.8
Environmental scientists	84.4	86.8	63.9	96.1	96.1	96.6
Earth scientists	82.3	84.8	63.4	95.5	95.4	96.6
Oceanographers	100.0	100.0	—	97.2	97.2	97.4
Atmospheric scientists	99.0	99.0	100.0	99.2	99.2	93.8
Engineers	93.5	93.6	86.7	93.4	93.4	92.5
Life scientists	68.2	71.5	56.3	94.0	94.4	91.2
Biological scientists	55.8	63.7	35.4	92.3	92.8	90.0
Agricultural scientists	70.9	72.5	45.7	94.3	94.7	79.5
Medical scientists	99.5	99.5	99.5	97.8	98.0	96.1
Psychologists	57.8	63.9	40.7	91.2	91.8	89.4
Social scientists	51.0	59.1	18.9	81.0	81.7	77.2
Economists	64.7	67.5	40.3	80.2	99.7	86.6
Sociologists and anthropologists	23.8	31.1	9.3	83.6	84.6	80.8
Other social scientists	54.7	63.5	19.6	80.3	81.7	72.2

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States: 1979* (NSF 80-323).

See figure 5-19.

Appendix Table 5-28. Average monthly salary offers to bachelor's degree candidates in selected fields: 1976/77 to 1978/79.

Curriculum	Average monthly salary offers 1976/77	1978/79	Percent change
Business	$ 927	$1,102	18.9
Humanities	810	983	21.4
Social sciences	887	1,020	15.0
Engineering:			
Chemical	1,389	1,642	18.2
Civil	1,185	1,402	18.3
Electrical	1,245	1,520	22.1
Mechanical	1,286	1,536	19.4
Agricultural sciences	924	1,046	13.2
Biological sciences	882	1,017	15.3
Chemistry	1,102	1,332	20.9
Computer sciences	1,123	1,401	24.8
Mathematics	1,073	1,324	23.4

SOURCES: CPC Salary Survey, *Final Report July 1978* and *Final Report July 1979,* (Bethlehem, Pa.: College Placement Council), p. 3.

See figure 5-20.

Science Indicators—1980

Appendix table 5-29. Average number of monthly salary offers to bachelor's degree candidates in selected fields: 1976/77 and 1978/79

Curriculum	Average number of monthly offers 1976/77	1978/79	Percent change
Business	3,649	4,796	31.4
Humanities	1,018	658	−35.4
Social sciences	1,275	1,947	52.9
Engineering:			
Chemical	4,026	6,310	56.7
Civil	2,178	4,424	103.1
Electrical	6,106	10,742	75.9
Mechanical	5,446	10,030	84.2
Agricultural sciences	652	557	−14.6
Biological sciences	238	244	2.5
Chemistry	331	379	14.5
Computer sciences	1,323	2,268	71.4
Mathematics	554	756	36.5

SOURCES: CPC Salary Survey, *Final Report July 1977* and *Final Report July 1979* (Bethlehem, Pa.: College Placement Council), p. 3.

Science Indicators—1980

Appendix table 5-30. Median annual salaries of full-time doctoral scientists and engineers[1] by field, sex and race: 1979

Field	Total	Sex: Men	Sex: Women	Race: White	Race: Black	Race: American Indian	Race: Asian
All S/E fields	$29,100	$29,900	$23,100	$29,200	$26,600	$25,800	$28,200
Physical scientists	30,300	30,500	24,400	30,400	28,000	(2)	27,800
Chemists	30,400	30,700	24,200	30,600	25,500	(2)	28,200
Physicists and astronomers	30,100	30,200	25,400	30,100	(2)	(2)	27,500
Mathematical scientists	26,300	26,700	21,700	26,400	25,100	(2)	25,700
Mathematicians	26,100	26,400	21,800	26,000	22,900	(2)	28,400
Statisticians	29,300	29,600	21,600	29,600	(2)	(2)	(2)
Computer specialists	28,500	28,800	22,800	28,400	(2)	(2)	29,800
Environmental scientists	30,300	30,400	23,500	30,300	(2)	(2)	25,800
Earth scientists	30,300	30,400	25,300	30,300	(2)	(2)	27,900
Oceanographers	28,800	30,100	21,500	28,800	(2)	(2)	(2)
Atmospheric scientists	31,300	31,800	(2)	31,600	(2)	(2)	(2)
Engineers	33,100	33,200	26,600	33,900	(2)	(2)	30,300
Life scientists	28,100	28,900	23,000	28,400	25,000	25,500	26,000
Biological scientists	26,500	27,500	22,200	26,700	25,600	(2)	24,800
Agricultural scientists	29,000	29,100	21,600	29,200	(2)	(2)	26,000
Medical scientists	30,900	32,700	25,300	31,200	26,500	(2)	28,400
Psychologists	26,700	28,000	23,200	26,600	24,800	30,100	25,400
Social scientists	26,200	26,800	22,600	26,100	28,000	(2)	25,200
Economists	31,000	31,500	26,900	30,900	(2)	(2)	35,300
Sociologists and anthropologists	23,900	25,000	22,100	23,800	23,900	(2)	24,300
Other social scientists	25,300	25,700	22,300	25,300	28,900	(2)	23,400

[1]Excludes the military services and the Commissioned Corps.
[2]Too few cases to estimate.

SOURCE: National Science Foundation, unpublished data.

Appendix table 5-31. Deutsch, Shea and Evans High Technology Recruitment Index: 1970-80

[1961 = 100]

Year	Index
1970	60
1971	43
1972	63
1973	97
1974	101
1975	68
1976	88
1977	115
1978	139
1979	144
1980	138

SOURCE: Deutsch, Shea and Evans, "High Technology Recruitment Index Year End Review and Forecast," (New York: Deutsch, Shea and Evans, Inc., 1981).

See figure 5-21. Science Indicators—1980

Appendix table 5-32. Median annual salaries of experienced scientists and engineers by field, sex and race: 1978

Field	Total	Sex		Race			
		Men	Women	White	Black	Asian	Other
All S/E fields	$27,200	$27,400	$22,600	$27,300	$24,900	$25,800	$24,300
Physical scientists	27,600	28,000	22,000	27,800	23,400	26,300	(2)
Mathematical scientists	27,500	27,900	24,100	27,700	26,600	26,800	(2)
Computer specialists	25,900	26,200	23,600	25,900	25,600	25,100	(2)
Environmental scientists[1]	30,400	30,500	24,700	30,400	(2)	(2)	(2)
Life scientists	24,900	25,200	21,900	25,000	22,200	22,800	21,700
Psychologists	26,500	27,300	23,800	26,500	28,500	(2)	(2)
Social scientists	27,600	28,700	21,000	27,700	22,000	(2)	(2)
Engineers	27,400	27,400	24,100	27,500	28,800	25,600	24,700

[1]Includes earth scientists, oceanographers, and atmospheric scientists.

[2]Too few cases to estimate.

SOURCE: National Science Foundation, *Characteristics of the Experienced Sample of Scientists and Engineers: 1978* (NSF 79-322), based on pp. 126-128.

See figures 5-22 and 5-23. Science Indicators—1980

Appendix table 5-33. Salaries and earnings of R & D scientists and engineers, production workers, and male professional and technical workers: 1970-79

Year	Median monthly salaries of R & D S/E's		Average hourly earnings of production workers		Annual earnings of male professional and technical workers	
	Dollars	Index (1970 = 100)	Dollars	Index (1970 = 100)	Dollars	Index (1970 = 100)
1970	$1,437	100.0	$3.23	100.0	$12,255	100.0
1971	1,512	105.2	3.45	106.8	12,518	102.1
1972	1,567	109.0	3.70	114.6	13,542	110.5
1973	1,632	113.6	3.94	122.0	14,306	116.7
1974	1,694	117.9	4.24	131.3	14,873	121.4
1975	1,828	127.2	4.53	140.2	15,796	128.9
1976	1,941	135.1	4.86	150.5	16,939	138.2
1977	2,060	143.4	5.25	162.5	18,244	148.7
1978	2,205	153.4	5.69	176.2	19,729	161.0
1979	NA	NA	6.16	190.7	NA	NA

NOTE: Earnings of professional and technical workers are for full-time year-round employees. Earnings of production workers are for those on private (non-public) payrolls.

SOURCES: U.S. Department of Labor, *Employment and Training Report of the President, 1979* p. 322; *Economic Report of the President, 1980*, p. 244; Batelle Columbus Laboratories, *National Survey of Compensation Paid Scientists and Engineers in Research and Development Activities* (1974, 1975 and 1978), Table 25 and U.S. Department of Labor, Bureau of Census, *Current Population Reports*, Series p. 60, No. 120, Table 9 (November 1979).

Appendix table 5-34. Distribution of employed scientists and engineers by field and minority group: 1978

Field	All S/E's	Minority scientists and engineers: All minorities	Blacks	Asians	Other
	Number				
All S/E fields	2,473,200	112,300	39,000	50,500	22,800
Engineers	1,268,400	38,300	10,600	26,400	1,300
Mathematical scientists	88,400	5,900	2,900	1,800	1,200
Computer specialists	233,900	8,100	1,100	6,900	100
Life scientists	291,000	11,600	6,600	4,600	400
Physical scientists	212,400	21,900	3,100	5,300	13,500
Environmental scientists[1]	72,200	2,700	700	600	1,400
Psychologists	120,900	4,000	3,300	([2])	700
Social scientists	186,000	19,700	10,600	5,100	4,000
	Percent				
All S/E fields	100.0	4.5	1.6	2.0	0.9
Engineers	100.0	3.0	.8	2.1	.1
Mathematical scientists	100.0	6.7	3.3	2.0	1.4
Computer specialists	100.0	3.5	.5	2.9	([3])
Life scientists	100.0	4.0	2.3	1.6	.1
Physical scientists	100.0	10.3	1.5	2.5	6.4
Environmental scientists[1]	100.0	3.7	1.0	.8	1.9
Psychologists	100.0	3.3	2.7	([2])	.6
Social scientists	100.0	10.6	5.7	2.7	2.2

[1]Includes earth scientists, oceanographers, and atmospheric scientists.
[2]Too few cases to estimate.
[3]Less than 0.05 percent.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *U. S. Scientists and Engineers: 1978* (NSF 80-304), based on pp. 16-17.

Science Indicators—1980

Appendix table 5-35. Number and percent of scientists and engineers by field and minority group: 1978

Field	All S/E's	Total minorities		Blacks		Asians		Other minorities	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent
All S/E fields	2,741,400	120,200	4.4	41,800	1.5	53,700	2.0	24,700	.9
Engineers	1,396,400	52,300	3.7	11,400	.8	27,000	1.9	13,900	1.0
Mathematical scientists	107,800	6,400	5.9	3,000	2.8	2,000	1.9	1,400	1.3
Computer specialists	237,500	8,400	3.5	1,400	.6	6,900	2.9	100	([1])
Life scientists	327,600	14,500	4.4	6,700	2.0	5,900	1.8	1,900	.6
Physical scientists	254,600	11,300	4.4	3,700	1.5	5,700	2.2	1,900	.7
Environmental scientists[2]	80,800	1,800	2.2	700	.9	600	.7	500	.6
Psychologists	131,700	4,600	5.7	3,700	4.6	100	.1	800	1.0
Social scientists	205,100	20,400	9.9	11,000	5.4	5,400	2.6	4,000	2.0

[1]Less than 0.05 percent.
[2]Includes earth scientists, oceanographers, and atmospheric scientists.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *U. S. Scientists and Engineers: 1978* (NSF 80-304), based on pp. 16-17.

Appendix table 5-36. Distribution of employed scientists and engineers by field and selected minority groups: 1978

Field	All S/E's		Black S/E's		Asian S/E's	
	Total employed	Percent	Total employed	Percent	Total employed	Percent
All S/E fields	2,473,200	100	39,000	100	50,500	100
Engineers	1,268,400	51	10,600	27	26,400	52
Mathematical scientists	88,400	4	2,900	7	1,800	4
Computer specialists	233,900	9	1,100	3	6,900	14
Life scientists	291,000	12	6,600	17	4,600	9
Physical scientists	212,400	9	3,100	8	5,300	10
Environmental scientists[1]	72,200	3	700	2	600	1
Psychologists	120,900	5	3,300	8	([2])	([2])
Social scientists	186,000	8	10,600	27	5,100	10

[1]Includes earth scientists, oceanographers, and atmospheric scientists.
[2]Too few cases to estimate.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *U.S. Scientists and Engineers: 1978* (NSF 80-304), based on pp. 16-17.

Science Indicators—1980

Appendix table 5-37. Number of scientists and engineers by highest earned degree and racial group: 1978

Highest earned degree	Total	White	Black	Asian	Other
Total	2,741,400	2,621,200	41,800	53,700	24,700
Doctorate	318,900	290,600	4,400	16,100	7,700
Master's	768,100	735,700	12,900	15,900	3,400
Bachelor's	1,588,800	1,534,000	24,100	20,600	10,300
Other[1]	65,600	61,300	200	1,000	3,000

[1]Includes professional, medical, associate, and other earned degrees.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *U.S. Scientists and Engineers: 1978* (NSF 80-304), based on pp. 26-30.

Science Indicators—1980

Appendix table 5-38. Unemployment rates of recent S/E bachelor's and master's degree recipients by field of degree: 1974-79

Year of survey	Year of degree	All S/E fields	Physical sciences[1]	Mathematical sciences[2]	Engineering	Life sciences	Social sciences[3]
		Bachelor's degree					
1974	1972	4.7	5.2	1.2	1.7	3.3	7.1
1976	1974	8.2	6.2	5.8	3.0	7.9	11.2
1978	1976	3.9	4.9	2.4	.7	4.2	5.0
1979	1977	3.9	2.4	.7	1.4	3.7	6.2
		Master's degree[4]					
1978	1976	3.3	2.1	4.1	0.8	3.3	5.8
1979	1977	2.3	.7	3.1	1.1	2.1	3.9

[1]Includes environmental sciences.
[2]Includes computer sciences.
[3]Includes psychology.
[4]Data were initially collected for master's degree graduates in 1976 survey; however, because of small sample size, unemployment rates by field are not considered statistically reliable prior to 1978.

NOTE: Unemployment rates defined as graduates who were not employed and seeking work as percent of total in labor force; i.e., employed plus unemployed. Includes graduate students if they reported that they were either employed or seeking work.

SOURCE: National Science Foundation, unpublished data.

See figure 5-25.

Science Indicators—1980

Appendix table 5-39. Unemployment and underemployment among recent science and engineering graduates by degree level and field of degree: 1979

Degree and field	Labor force	Unemployed or underemployed: Unemployed but seeking employment: Number	Percent of labor force	Involuntary part-time: Number	Percent of labor force	Involuntary non-S/E job: Number	Percent of labor force	Total: Number	Percent of labor force
Bachelor's degree graduates (1977):									
All S/E fields	248,700	9,700	3.9	5,700	2.3	21,600	8.7	37,100	14.9
Physical sciences[1]	19,900	500	2.4	500	2.6	1,200	6.0	2,200	11.0
Mathematical sciences[2]	19,500	100	.7	400	2.2	800	4.1	1,400	7.0
Engineering	48,100	700	1.4	300	.6	([4])	—	1,000	2.1
Life sciences	59,300	2,200	3.7	1,700	3.9	6,100	10.2	10,000	16.8
Social sciences[3]	101,500	6,300	6.2	2,700	2.7	13,500	13.2	22,500	22.2
Master's degree graduates (1977):									
All S/E fields	51,600	1,208	2.3	900	1.6	1,100	2.2	3,200	6.1
Physical sciences[1]	5,000	([4])	—	100	2.0	([4])	—	200	3.6
Mathematical sciences[2]	6,100	200	3.1	([4])	—	100	1.4	300	4.9
Engineering	16,300	200	1.1	200	1.0	([4])	—	300	2.1
Life sciences	9,300	200	2.1	200	2.4	200	2.5	700	7.0
Social sciences[3]	14,800	600	3.9	300	2.3	800	5.1	1,700	11.3

[1]Includes environmental sciences.
[2]Includes computer sciences.
[3]Includes psychologists.
[4]Less than 50.

SOURCE: National Science Foundation, unpublished data.

See figure 5-26.

Science Indicators—1980

Appendix table 5-40. Unemployment and underemployment rates for 1977 S/E graduates, by degree level, field and sex: 1979

Level	Survey year	All S/E fields		Physical sciences[1]		Mathematical sciences[2]		Engineering		Life sciences		Social sciences[3]	
		Men	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
		Unemployment rates											
Bachelor's degree	1979	3.3	5.2	1.7	4.7	0.9	0.5	1.1	6.4	3.3	4.5	6.1	6.3
Master's degree	1979	1.6	4.9	.5	2.1	3.5	1.8	1.1	([4])	2.6	5.6	5.5	6.3
Doctorates	1977	1.6	5.3	1.5	6.5	.5	([4])	1.0	([4])	1.6	4.3	2.1	5.6
		Underemployment rates[5]											
Bachelor's degree	1979	9.5	14.2	8.0	11.2	6.3	6.1	.8	0.0	14.9	9.3	13.9	18.4
Master's degree	1979	3.6	4.7	2.6	4.1	1.8	1.8	1.1	([4])	4.3	1.6	4.2	7.9
Doctorates	1977	4.8	7.4	6.8	6.3	6.5	([4])	1.8	([4])	3.2	3.8	5.7	9.8

[1]Includes environmental science.
[2]Includes computer sciences.
[3]Includes psychology.
[4]Sample size insufficient to estimate.
[5]Underemployment rates for bachelor's and master's degree graduates include part-time workers seeking full-time jobs and persons employed full-time in non-science and engineering jobs because an S/E position was not available. Underemployment rates for doctorates include part-time workers seeking full-time jobs and those employed full-time outside of their doctoral field because positions in their field were not available. These rates are therefore *not* strictly comparable with the corresponding rates for bachelor's and master's degree graduates.

SOURCE: National Science Foundation, unpublished data.

See figure 5-27.

Appendix table 5-41. Employment status of 1977 bachelor's degree recipients two years after graduation by field of study: 1979

Field of study	Total population	Labor force: Total	Employed: Total employed: Total	Total employed: Full-time	Total employed: Part-time	Employed in S/E jobs: Total	Employed in S/E jobs: Full-time	Employed in S/E jobs: Part-time	Employed in non-S/E jobs: Total	Employed in non-S/E jobs: Full-time	Employed in non-S/E jobs: Part-time	Unemployed but seeking employment	Outside labor force	Full-time graduate students[1]
	Number													
All S/E fields	298,640	248,680	238,930	202,630	36,290	123,270	104,630	18,640	115,650	98,000	17,650	9,750	49,970	76,480
Physical scientists[2]	26,220	19,930	19,460	15,730	3,720	13,820	10,960	2,870	5,630	4,770	860	470	6,300	10,020
Mathematical scientists[3]	20,730	19,530	19,390	17,550	1,840	13,740	12,870	870	5,640	4,680	960	150	1,200	2,720
Engineers	49,930	48,080	47,400	45,540	1,840	44,140	42,860	1,280	3,270	2,680	590	680	1,850	4,110
Life scientists	78,870	59,610	57,430	46,140	11,290	31,530	25,300	6,230	25,900	20,840	5,060	2,190	19,250	26,520
Social scientists[4]	122,890	101,520	95,250	77,670	17,580	20,040	12,640	7,400	75,200	65,030	10,190	6,270	21,370	33,120
	Percent													
All S/E fields	100.0	83.3	80.0	67.8	12.2	41.3	35.0	6.2	38.7	32.8	5.9	3.3	16.7	25.6
Physical scientists[2]	100.0	76.0	74.2	60.0	14.2	52.7	41.8	10.9	21.5	18.2	3.3	1.8	24.0	38.2
Mathematical scientists[3]	100.0	94.2	93.5	84.6	8.9	66.3	62.1	4.2	27.2	22.6	4.6	.7	5.8	19.8
Engineers	100.0	96.3	94.9	91.2	3.7	88.4	85.8	2.6	6.5	5.4	1.1	1.4	3.7	8.2
Life scientists	100.0	75.6	72.8	58.5	14.3	40.0	32.0	7.9	32.8	26.4	6.4	2.8	24.4	33.6
Social scientists[4]	100.0	82.6	77.5	63.2	14.3	16.3	10.3	6.0	61.2	52.9	8.3	5.1	17.4	26.9

[1]These students may also be included in other columns of this table.
[2]Includes environmental scientists.
[3]Includes computer specialists.
[4]Includes psychologists.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See figure 5-24.

Appendix table 5-42. Transition of 1977 S/E bachelor's and master's degree recipients from school to work: 1979

Status in 1979	Bachelor's degree recipients	Master's degree recipients
Total	298,600	56,400
Full-time graduate students	76,500	11,100
Employed	238,900	50,400
In S/E jobs	123,300	39,300
In non-S/E jobs	115,700	11,100
Unemployed and seeking	9,700	1,200
Not in the labor force	50,000	4,800

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

Science Indicators—1980

Appendix table 5-43. Employed 1977 S/E bachelor's degree recipients working in science and engineering by field of study and sex: 1979

Field of study	Total employed		Employed in S/E jobs: Number		Employed in S/E jobs: Percent	
	Men	Women	Men	Women	Men	Women
All S/E fields	162,600	76,400	93,000	30,300	57.2	39.7
Physical sciences[1]	15,300	4,100	11,100	2,700	72.5	65.9
Mathematical sciences[2]	12,400	7,000	8,800	4,900	71.0	70.0
Life sciences	38,200	19,200	20,600	10,900	53.9	56.8
Social sciences[3]	51,500	43,700	10,400	9,600	20.2	22.0
Engineers	45,100	2,300	42,000	2,200	93.1	95.7

[1]Includes environmental sciences.
[2]Includes computer sciences.
[3]Includes psychology.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

Science Indicators—1980

Appendix table 5-44. Median annual salaries of 1977 S/E graduates employed full-time in S/E by sex, degree level, and field of work: 1979

Field	Male	Female	Female/male salary ratio
	1977 bachelor's degree recipients		
All S/E fields	$17,036	$13,148	0.772
Physical scientists	14,018	13,958	.996
Mathematical scientists	15,724	15,029	.956
Computer specialists	17,150	16,395	.956
Engineers	18,536	17,035	.919
Life scientists	11,196	11,012	.984
Psychologists	10,014	10,109	1.009
Social scientists	12,476	12,144	.973
	1977 Master's degree recipients		
All S/E fields	$20,022	$15,031	.751
Physical scientists	17,530	15,008	.856
Mathematical scientists	15,485	15,645	1.010
Computer specialists	21,841	20,015	.916
Engineers	21,665	19,247	.888
Life scientists	15,468	12,858	.831
Psychologists	14,222	12,400	.872
Social scientists	18,164	16,044	.883

SOURCE: National Science Foundation, unpublished data.

See figure 5-28. Science Indicators—1980

Appendix table 5-45. Unemployment rates of recent S/E graduates by race and degree level: 1976-79

Degree level and survey year	All S/E fields		Social sciences		All other S/E fields	
	White	Black	White	Black	White	Black
Bachelor's degrees:						
1976[1]	8.7	11.9	11.9	12.2	6.4	11.2
1978/79[2]	3.4	10.5	4.6	12.6	2.5	5.0
Master's degrees:						
1976[1]	3.9	10.9	6.5	(3)	2.8	(3)
1978/79[2]	2.6	6.8	4.6	12.2	1.7	(3)

[1]Data include both 1974 and 1975 graduates.
[2]Data include 1976 and 1977 graduates, based on a pooling of the 1978 and 1979 survey data.
[3]Sample size insufficient to estimate.

SOURCE: National Science Foundation, unpublished data.

See figure 5-29. Science Indicators—1980

Appendix table 5-46. Primary work activity of 1977-78 doctoral recipients in science and engineering: 1979

Primary work activity	Year of doctorate			
	1977		1978	
	Number	Percent	Number	Percent
Total	15,800	100.0	16,100	100.0
Research and development	8,200	51.9	9,100	56.5
Basic research	3,700	23.4	4,400	27.3
Applied research	2,800	17.7	2,300	14.3
Development	500	3.2	1,000	6.2
Management of R&D	1,200	7.6	1,400	8.7
Teaching	3,900	24.7	3,800	23.6
Management and administration	700	4.4	700	4.3
Consulting	500	3.2	300	1.9
Sales and professional services	1,600	10.1	1,400	8.7
Other activities	800	5.1	700	4.3
Activity not reported	100	.6	200	1.2
Not employed	800	—	700	—

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See figure 5-33.

Science Indicators—1980

Appendix table 5-47. Selected characteristics of employed 1977 bachelor's degree recipients, two years after graduation by type of employer, field, and primary work activity: 1979

	All S/E fields	Physical scientists[1]	Mathematical scientists[2]	Engineers	Life scientists	Social scientists[3]
Total employed	238,900	19,500	19,400	47,400	57,400	95,300
By type of employer:						
Business and industry	134,500	9,200	12,200	39,100	25,800	48,300
Educational institutions	38,800	5,200	4,600	2,300	13,400	13,300
Nonprofit organizations	11,300	600	500	100	1,800	8,100
Federal Government[4]	12,800	1,400	400	2,300	4,000	4,700
State and local government	20,600	1,400	600	1,500	4,700	12,400
Other employers	21,000	1,600	1,100	2,100	7,700	8,500
By primary work activity:						
Research and development performance	51,300	5,900	2,800	18,600	13,400	10,600
Management of R&D	4,400	400	200	1,200	600	2,000
Management and administration	29,500	1,400	800	3,300	6,500	17,600
Teaching	28,800	2,500	3,700	1,500	6,800	14,100
Production and inspection	42,200	4,300	1,400	12,500	14,300	9,700
Reporting, statistical work, computing	37,200	2,500	8,900	6,400	4,400	15,100
Sales and professional services	36,700	1,800	800	2,600	10,400	21,100
Other activities	8,800	600	800	100	1,200	5,000

[1]Includes environmental scientists.
[2]Includes computer specialists.
[3]Includes psychologists.
[4]Civilian employment only.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See figures 5-30, 5-31 and 5-33.

Science Indicators—1980

Appendix table 5-48. Selected characteristics of employed 1977 master's degree recipients, two years after graduation by type of employer, field, and primary work activity: 1979

	All S/E fields	Physical scientists[1]	Mathematical scientists[2]	Engineers	Life scientists	Social scientists[3]
Total employed	50,400	5,000	5,900	16,100	9,100	14,300
By type of employer:						
Business and industry	21,000	2,200	2,500	10,800	2,500	3,000
Educational institutions	14,300	1,500	2,000	2,000	3,900	4,900
Nonprofit organizations	1,800	100	100	300	200	1,200
Federal Government[4]	4,700	600	600	1,200	1,000	1,200
State and local government	4,500	500	100	1,000	900	2,000
Other	4,200	100	600	800	700	2,000
By primary work activity:						
Research and development performance	15,900	2,200	1,100	7,800	2,900	1,900
Management of R&D	2,000	200	200	500	500	600
Management and administration	6,200	500	500	2,300	900	2,100
Teaching	8,200	700	1,800	400	1,900	3,400
Production and inspection	4,800	600	300	2,100	1,100	800
Reporting, statistical work, computing	7,700	800	1,900	2,000	1,000	2,000
Sales and professional services	3,600	100	100	200	500	2,700
Other	2,100	([5])	100	900	300	800

[1]Includes environmental scientists.
[2]Includes computer specialists.
[3]Includes psychologists.
[4]Civilian employment only.
[5]Less than 50.

NOTE: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, unpublished data.

See figures 5-30, 5-31 and 5-33.

Appendix table 6-1. Beneficial versus harmful consequences of science and technology: 1972-78

Science and technology do	Percent 1972	1974	1976	1978
More good than harm	54	57	52	60
More harm than good	4	2	4	5
About the same	31	31	37	28
Don't know	11	10	7	6
	(N = 2,209)	(N = 2,074)	(N = 2,108)	(N = 1,500)

NOTE: The question discussed here differs from the 1979 question on text table 6-1. In 1979, only "more good than harm" and "more harm than good" were offered to the respondents as choices. However, some volunteered "about the same." In 1972-76, all three choices were offered to the respondents. As a result, in 1979 the percentage responses to the first two choices are higher than in previous years.

SOURCES: 1972-76: *Attitudes of the U. S. Public Toward Science and Technology.* Study III (Princeton, N.J.: Opinion Research Corporation, 1976), p. 21. 1978: *An Analysis of Public Attitudes Toward Technology and Investment* (Boston: Cambridge Reports, Inc. for Union Carbide Corporation, 1978), p. 14.

Science Indicators—1980

Appendix table 6-2. Percent distribution of perceived benefits and harms from scientific research: 1979

Group	Percent: Harms outweigh benefits: Strongly	Harms outweigh benefits: Slightly	Benefits & harms about equal	Benefits outweigh harms: Slightly	Benefits outweigh harms: Strongly	Number of respondents
All adults	4	7	13	24	46	1,635
By age						
18 to 24	8	10	8	29	41	309
25 to 34	2	4	14	27	49	361
35 to 44	2	7	16	23	50	258
45 to 54	4	5	13	20	51	234
55 to 64	3	8	14	21	48	228
65 and over	4	7	14	24	38	245
By gender						
Male	3	7	11	23	51	773
Female	4	6	15	25	42	862
By education						
Less than high school	6	12	17	25	27	465
High-school diploma	2	7	13	25	49	550
Some college, no degree	5	3	11	27	52	382
Bachelor's degree	1	1	12	19	67	146
Graduate degree	5	5	3	15	72	92
By attentiveness						
Attentive public	2	2	6	19	71	301
Nonattentive public	4	8	14	25	41	1,334

NA = Not available.

SOURCE: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U. S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), p. 69.

See table 6-1 in text.

Science Indicators—1980

Appendix table 6-3. Proportion of general public feeling that science changes life too fast: 1957-79

Year	Percent	Sample size
1957	43	1,919
1958	47	NA
1964	57	NA
1968	54	NA
1979	53	1,635

NA = Not available.

SOURCES: 1957: *The Public Impact of Science in the Mass Media* (Ann Arbor, Mich.: Survey Research Center, University of Michigan for the National Association of Science Writers, 1958), p. 186.

1958, 1964: Studies by the Survey Research Center, University of Michigan and by the National Opinion Research Center, University of Chicago, cited by Karen Oppenheim, "Acceptance and Distrust of American Adults Toward Science," unpublished Master's thesis, University of Chicago, 1966.

1968: Supplement for Question 61 of Study SRS-4050 (Chicago: National Opinion Research Center, University of Chicago, 1968).

1979: Koray Tanfer, Eugene Ericksen, and Lee Robeson, *National Survey of the Attitudes of the U.S. Public Toward Science and Technology.* Volume II: Detailed Findings (Philadelphia: Institute for Survey Research, Temple University, 1980), p. 124.

See table 6-3 in text.

Science Indicators — 1980

Appendix table 6-4. Two factors that contribute most and least to U.S. influence in the world: 1979

Factor	Percent		
	First mention	Second mention	Total
Contribute most:			
Our economic system	19	7	27
Our technological know-how	17	29	46
Our scientific creativity	17	5	22
Our natural resources	14	5	19
Our religious heritage	12	3	15
The racial and ethnic mixture of our population	6	4	11
Our form of government	6	35	41
Our educational system	6	8	14
Don't know	2	3	5
Contribute least:			
The racial and ethnic mixture of our population	29	18	47
Our religious heritage	24	25	49
Our natural resources	13	6	19
Our educational system	9	16	25
Our economic system	9	4	12
Our scientific creativity	6	3	9
Our form of government	2	10	12
Our technological know-how	2	7	8
Don't know	6	11	18

NOTE: Sample size was 1,635.

SOURCE: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U.S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), pp. 251-253.

See table 6-4 in text.

Science Indicators — 1980

Appendix table 6-5. Public's identification of major factors that will make America great: 1973-79

Factor[1]	Percent			
	1973	1975	1977	1979
Scientific research	NA	NA	91	89
Industrial know-how	87[2]	86[2]	80	80
Rich natural resources	65	79	77	79
Hard-working people	74	78	76	79
A government that responds to the people's needs	NA	NA	70	78
Skill at organizing production	NA	NA	71	74
Democracy as its political system	NA	NA	72	74
Technological genius	NA	NA	78	73
A highly motivated labor force	NA	NA	64	72
Giving every race and creed an equal chance to get ahead	NA	76	70	70
The availability of money to expand industry	NA	NA	71[3]	69
Free, unlimited education to all qualified	78	75	75	67
Outstanding political leaders	60	53	51	62
A talent for selling and marketing things	NA	NA	61	60
Freedom of thought in the universities	NA	NA	67	60
Having industry and business under private control	66	67	58	59
Deep religious beliefs	NA	NA	61	57
Advertising	NA	NA	49	41
Heavy government spending for social programs	NA	NA	NA	31
Having a government which regulates industry	69[4]	65[4]	36	27
People of different racial and religious backgrounds	57	58	NA	NA
Welcoming refugees from all over the world	NA	NA	53[5]	24
	(N = 1,513)	(N = 1,519)	(N = 1,498)	(N = 1,514)

[1]Factors chosen as making a major contribution to America's greatness in the next 10 years (for 1973 and 1975) and in the next 25 years (for 1977 and 1979). Multiple responses were accepted.
[2]Wording in 1973 and 1975 was "Industrial know-how and scientific progress."
[3]Wording in 1977 was "The availability of capital."
[4]Wording in 1973 and 1975 was "Having a government which regulates business abuses."
[5]Wording in 1977 was "Welcoming refugees with scientific backgrounds from all over the world."

NA = Not available.

SOURCES: The Harris Survey, Releases dated August 23, 1973; November 27, 1975; January 16, 1978; and March 6, 1980.

See table 6-5 in text.

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Appendix table 6-6. Proportion expecting scientific and technological achievements in 25 years: 1979

Achievement and respondent group	Percent who believe achievements are: Very likely	Possible	Not likely	Sample size
More efficient sources of cheap energy				
Total public	57	34	7	1,635
Nonattentives	52	38	8	1,334
Attentives	81	16	3	301
A way to predict when and where earthquakes will occur				
Total public	52	38	8	1,635
Nonattentives	48	42	9	1,334
Attentives	74	24	2	301
A cure for the common forms of cancer				
Total public	46	44	8	1,635
Nonattentives	43	47	8	1,334
Attentives	59	33	7	301
A way to economically desalinate sea water for human consumption				
Total public	43	42	10	1,635
Nonattentives	38	44	12	1,334
Attentives	63	34	4	301
A way to put communities of people in outer space				
Total public	17	38	42	1,635
Nonattentives	14	37	45	1,334
Attentives	28	42	29	301
New ways of effectively reducing the crime rate				
Total public	14	41	42	1,635
Nonattentives	14	41	42	1,334
Attentives	14	41	44	301

SOURCE: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U. S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), p. 72; Koray Tanfer, Eugene Ericksen, and Lee Robeson, *National Survey of the Attitudes of the U.S. Public Toward Science and Technology.* Volume II: Detailed Findings (Philadelphia: Institute for Survey Research, Temple University, 1980), pp. 204-209; Jon D. Miller, unpublished data.

See table 6-6 in text. Science Indicators — 1980

Appendix table 6-7. Percent distribution of level of public expectations from science and technology: 1979

Group	Level[1]: 0	1-3	4-6	Number of respondents
All adults	20	54	27	1,635
By age				
18 to 24	25	57	18	309
25 to 34	15	60	26	361
35 to 44	20	53	28	258
45 to 54	15	52	33	234
55 to 64	19	51	31	228
65 and over	25	47	28	245
By gender				
Male	17	52	31	773
Female	22	55	23	862
By education				
Less than high school	32	48	20	463
High-school diploma	18	58	24	550
Some college, no degree	14	53	33	382
Bachelor's degree	15	56	29	146
Graduate degree	5	54	41	92
By attentiveness				
Attentive public	5	51	45	301
Nonattentive public	23	54	23	1,334

[1]This value is the number of achievements on appendix table 6-6 that the respondent considered very likely.

SOURCE: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U. S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), p. 74.

See table 6-6 in text. Science Indicators — 1980

Appendix table 6-8. Proportion opposing selected areas of scientific inquiry: 1979

Scientists should not conduct studies for—	Percent of Attentives	Percent of Nonattentives	Percent of Total public
Creating new forms of life	49	69	65
Enabling most people to live to be 100 or more	19	32	29
Precise weather control and modification	20	30	28
Detecting criminal tendencies in very young children	13	17	16
Discovering intelligent beings in outer space	10	42	36
	(N = 301)	(N = 1,334)	(N = 1,635)

SOURCES: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U. S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), p. 82; Koray Tanfer, Eugene Ericksen, and Lee Robeson, *National Survey of the Attitudes of the U. S. Public Toward Science and Technology.* Volume II: Detailed Findings (Philadelphia: Institute for Survey Research, Temple University, 1980), pp. 210-214; Jon D. Miller, unpublished data.

See table 6-7 in text.

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Appendix table 6-9. Public opinion in nine European countries regarding experiments on hereditary transmissions[1]: 1978

Country	Percent who believe they: Are worthwhile	Percent who believe they: Carry unacceptable risk	Sample size
Denmark	13	61	983
West Germany	22	45	1,000
Netherlands	36	41	1,083
France	29	37	1,340
United Kingdom	32	36	1,306
Belgium	38	22	1,014
Ireland	41	22	1,006
Italy	49	22	919
Luxembourg	37	18	330
All nine countries	33	35	9,018

[1]The research was described as "to carry out experiments on the transmission of hereditary characteristics which could make it possible to improve the qualities of living species."

SOURCE: Opinion Poll in the Countries of the European Community. XII/201/79-EN (Brussels: Commission of the European Communities, 1979), p.41.

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Appendix table 6-10. Areas the public would most like to receive science and technology funding from tax money: 1972-79

Area	Percent in 1979	Rank[1]			
		1972	1974	1976	1979
Improving health care	50	1	1	1	1
Developing energy sources and conserving energy	46	(2)	(2)	(2)	(2)
Improving education	39	5	4[3]	3[3]	2
Reducing crime	36	3	2	2	3
Developing or improving methods for producing food	23	(2)	(2)	(2)	(2)
Reducing and controlling pollution	22	2	3	3[3]	4
Developing or improving weapons for national defense	16	10[3]	11[3]	8[3]	5[3]
Preventing and treating drug addiction	16	4	4[3]	5	5[3]
Developing faster and safer public transportation within and between cities	13	7	7	7	7
Improving the safety of automobiles	9	6	6	6	8
Finding better birth control methods	9	8	9	8[3]	9
Discovering new basic knowledge about man and nature	8	9	8	10	10
Exploring outer space	6	10[3]	11[3]	11	11
Predicting and controlling the weather	4	10[3]	10	12	12
	(N = 1,635)				

[1] In 1979, respondents were asked to limit themselves to three areas, and slight changes in the wording of some items were made.
[2] "Developing energy sources and conserving energy" was not included in the listing prior to 1979 and "developing or improving methods for producing food" was not included prior to 1976. These areas were therefore omitted from the rankings.
[3] Tied for the indicated rank.

SOURCES: *Attitudes of the U. S. Public Toward Science and Technology.* Study III (Princeton, N.J.: Opinion Research Corporation, 1976), pp. 56-57; Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U. S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), p. 137.

See table 6-8 in text.

Appendix table 6-11. Areas the public would least like to receive science and technology funding from tax money: 1972-79

Area	Percent in 1979	Rank[1] 1972	1974	1976	1979
Exploring outer space	43	1	1	1	1[2]
Finding better birth control methods	43	4	3	3	1[2]
Predicting and controlling the weather	36	3	4	4	3
Discovering new basic knowledge about man and nature	35	5	5	5	4
Developing faster and safer public transportation within and between cities	26	6	6	6	5
Developing or improving weapons for national defense	25	2	2	2	6
Improving the safety of automobiles	17	7	7	7	7
Developing or improving methods for producing food	15	([3])	([3])	([3])	([3])
Preventing and treating drug addiction	12	8[2]	8	8[2]	8
Reducing and controlling pollution	7	10	9[2]	11	9
Reducing crime	5	11	11	10	10
Improving health care	4	12	12	12	11
Improving education	3	8[2]	9[2]	8[2]	12
Developing energy sources and conserving energy	2	([3])	([3])	([3])	([3])
	(N = 1,635)				

[1]In 1979, respondents were asked to limit themselves to three areas, and slight changes in the wording of some items were made.
[2]Tied for the indicated rank.
[3]"Developing energy sources and conserving energy" was not included in the listing prior to 1979 and "developing or improving methods for producing food" was not included prior to 1976. These areas were therefore omitted from the rankings.

SOURCES: *Attitudes of the U. S. Public Toward Science and Technology.* Study III (Princeton, N.J.: Opinion Research Corporation, 1976), pp. 58-59; Koray Tanfer, Eugene Ericksen, and Lee Robeson, *National Survey of the Attitudes of the U. S. Public Toward Science and Technology.* Volume II: Detailed Findings (Philadelphia: Institute for Survey Research, Temple University, 1980), pp. 216-231.

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Appendix table 6-12. Proportion of public believing that the U.S. is spending too little in each area: 1973-80

Area	Percent 1973	1976	1978	1980
Halting the rising crime rate	64	65	64	69
Dealing with drug addiction	65	58	55	59
The military, armaments, and defense	11	24	27	56
Improving and protecting the nation's health	61	60	55	55
Improving the nation's education system	49	50	52	53
Improving and protecting the environment	61	55	52	48
Solving the problems of the big cities	48	42	39	40
Improving the conditions of blacks	32	27	24	24
Space exploration program	7	9	12	18
Welfare	20	13	13	13
Foreign aid	4	3	4	5
Number of respondents	1,504	1,499	1,532	1,468

SOURCE: James A. Davis, Tom W. Smith, C. Bruce Stephenson, *General Social Surveys, 1972-1980: Cumulative Codebook* (Chicago: National Opinion Research Center, University of Chicago, 1980), pp. 71-74.

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Appendix table 6-13. Expected benefits and harms from space exploration: 1979

	Percent		
	Total	First mention	Second mention
Benefits			
Improve other technologies (i.e., computers)	39	30	9
Increase knowledge of universe and/or of man's origins	28	20	8
Find mineral or other wealth, other resources, sources of energy	28	16	12
Find new areas for future habitation	19	10	9
Contact other civilizations, other forms of life	15	9	6
Improves rocketry and missile (military) technology	6	3	3
Find industrial use for space	4	2	2
Find new kinds of food/places to raise more food products	3	1	2
Creates jobs and other economic benefits	2	1	1
Learn about weather and how to control it	2	1	1
Other responses	3	2	1
Don't know	50	5	45
	(N = 697)		
Harms			
Bring back other diseases or problems	30	23	7
Disturbs the weather, messing up atmosphere	23	18	5
Too expensive, waste of money	22	17	5
Falling debris, leaving garbage in space	16	10	6
Dangerous for space explorers	13	9	4
Contact other civilizations that might conquer us	10	7	3
Improve weaponry; move warfare to space; increase political tensions on earth	9	6	3
Not the will of God; against the Bible	2	1	1
Other responses	6	3	3
Don't know	68	5	63
	(N = 401)		

[1]Two benefits and two harms were requested. Percentages are based on those who have heard of controversies in this area and who say there are benefits or harms, not on the entire sample.

SOURCE: Koray Tanfer, Eugene Ericksen, and Lee Robeson, *National Survey of the Attitudes of the U. S. Public Toward Science and Technology.* Volume II: Detailed Findings (Philadelphia: Institute for Survey Research, Temple University, 1980), pp. 151-154, 156-158.

See table 6-9 in text.

Appendix table 6-14. Distribution of benefits and harms expected in specific issue areas by attentives, non-attentives, and the total public: 1979

Issue area and consequences	Percent of[1]		
	Attentives	Nonattentives	Total public
Space exploration			
Benefits and no harms	61	36	42
Both benefits and harms	31	28	29
Neither benefits nor harms	6	19	16
Harms and no benefits	3	16	13
	(N = 252)	(N = 734)	(N = 986)
Chemical food additives			
Benefits and no harms	7	10	10
Both benefits and harms	79	43	49
Neither benefits nor harms	3	14	12
Harms and no benefits	12	34	30
	(N = 294)	(N = 1,210)	(N = 1,504)
Nuclear power plant location			
Benefits and no harms	20	16	17
Both benefits and harms	50	45	46
Neither benefits nor harms	0	6	5
Harms and no benefits	29	33	32
	(N = 300)	(N = 1,194)	(N = 1,494)

[1]Percentages are based on those who have heard of controversies in each area, not on the entire sample.

SOURCE: Based on Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U. S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), p. 120.

See table 6-10 in text.

Appendix table 6-15. Perceived benefits and harms from chemical food additives: 1979

	Percent[1]		
	Total	First mention	Second mention
Benefits			
Improve shelf life, retard spoilage, kills germs, preserves	85	80	5
Improves taste, color, consistency, or appearance	35	8	27
Improves nutrition, adds vitamins	24	7	17
Improves processing of the food	4	2	2
Prevents infestation	2	1	1
Other responses	4	2	2
Don't know	46	1	45
	(N = 891)		
Harms			
Causes cancer or suspected of causing cancer in laboratory animals or humans	68	59	9
Causes other diseases or illnesses, birth defects	31	14	17
Generally "not good for you," or "harms the body"	21	13	8
Reduces nutritional value of food	9	4	5
Causes hyperactivity in children	9	4	5
Negatively affects taste, color, consistency, or appearance	6	2	4
Other responses	2	1	1
Don't know	54	2	52
	(N = 1,189)		

[1] Two benefits and two harms were requested. Percentages are based on those who have heard of controversies in this area and who say there are benefits or harms, not on the entire sample.

SOURCE: Koray Tanfer, Eugene Ericksen, and Lee Robeson, *National Survey of the Attitudes of the U. S. Public Toward Science and Technology.* Volume II: Detailed Findings (Philadelphia: Institute for Survey Research, Temple University, 1980), pp. 134-135, 137-139.

See table 6-11 in text.

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Appendix table 6-16. Expected benefits and harms from nuclear power plants: 1979

	Percent[1]		
	Total	First mention	Second mention
Benefits			
Increase the supply of energy, solve our power shortage	65	59	6
Produce cheaper energy, less expensive than other energy sources	35	22	13
Reduce importation of foreign oil, reduce balance of payments problems, reduce foreign dependence	12	5	7
Improve economy, produce more jobs	8	2	6
Rely less on fossil fuels, conserve our fossil fuels	8	3	5
Produce cleaner energy, no air pollution from burning coal or oil	7	2	5
Improve our standard of living, lead to technological progress	5	2	3
Learn more about use of nuclear power and learn how to improve safety	2	1	1
Would have military use, help in national defense	2	1	1
Other responses	2	0	2
Don't know	55	3	52
	(N = 934)		
Harms			
Possibility of melt-down, nuclear explosion, or other catastrophic accident (Three Mile Island type situation)—human error leading to accident	45	36	9
Low level radiation leaks to surrounding area	42	31	11
Problems in disposal and maintenance of used nuclear material	24	13	11
Health risks to nonworkers, genetic risks, danger to unborn children, cancer	22	7	15
Heat pollution or other environmental damage	11	3	8
It's just unsafe (nonspecific)	9	5	4
Increased energy costs	3	1	2
Susceptibility to terrorism or terrorists	2	1	1
Dangers to the health of nuclear workers	1	0	1
Other responses	3	1	2
Don't know	37	1	36
	(N = 1,166)		

[1]Two benefits and two harms were requested. Percentages are based on those who have heard of controversies in this area and who say there are benefits or harms, not on the entire sample.

SOURCES: Koray Tanfer, Eugene Ericksen, and Lee Robeson, *National Survey of the Attitudes of the U.S. Public Toward Science and Technology.* Volume II: Detailed Findings (Philadelphia: Institute for Survey Research, Temple University, 1980), pp. 175-178, 180-183.

See table 6-12 in text.

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Appendix table 6-17. Proportions favoring or opposing the building of more nuclear power plants in the United States: 1975-80

Date of survey	Percent			Sample size
	Favor	Oppose	Not sure	
March 1975	63	19	18	1,537
April 1976	44	35	21	1,502
July 1976	61	22	17	1,497
May 1977	59	25	16	1,540
March 1978	55	25	19	1,529
September 1978	57	31	12	1,556
(March 1979—Three Mile Island incident)				
April 4-5, 1979	52	42	6	1,200
April 6-9, 1979	47	45	8	1,200
April 4-16, 1979	44	43	13	1,510
May 18-22, 1979	52	42	6	1,498
June 2-6, 1979	51	41	8	1,237
June 14-17, 1979	51	41	8	1,197
June 29-July 2, 1979	53	40	7	1,496
August 3-5, 1979	56	37	7	1,200
September 7-8, 1979	50	40	10	1,200
September 21-23,1979	52	37	11	1,200
October 5-7, 1979	44	45	11	1,200
October 19-21, 1979	45	43	12	1,197
November 2-4, 1979	42	47	11	1,199
November 16-18, 1979	48	42	10	1,197
November 30-December 2, 1979	49	41	10	1,494
December 14-16, 1979	48	40	12	1,195
December 27-30, 1979	48	39	13	1,516
January 10-13, 1980	51	37	12	1,498
January 24-27, 1980	50	39	11	1,196
February 7-10, 1980	50	40	10	1,197
February 21-24,1980	45	44	11	1,196
April 17-20, 1980	47	46	7	1,198
April 26-30, 1980	47	45	8	1,190
June 13-15, 1980	50	40	10	1,195
July 25-27, 1980	48	40	12	1,203
September 7-11, 1980	49	42	9	1,193
October 11-13, 1980	52	39	9	1,200
November 7-10, 1980	47	47	6	1,199
December 1-8, 1980	50	40	10	1,200

NOTE: The survey covers adults 18 years old and older in the 48 contiguous states. Personal interviewing was employed in 1975-78 and telephone interviewing in 1979-80. The response "not sure" was not offered to the respondents, but was volunteered by some.

SOURCES: March 1975: Louis Harris and Associates, *A Survey of Public and Leadership Attitudes Toward Nuclear Power Development in the United States* (New York: Ebasco Services, Inc., 1975); July 1976: Louis Harris and Associates, *A Second Survey of Public and Leadership Attitudes Toward Nuclear Power Development in the United States* (New York: Ebasco Services, Inc., 1976); April 1976 and May 1977-September 1978: Louis Harris, *The Harris Survey* (New York: The Chicago Tribune—New York News Syndicate, 1976-78); April-May 1979 and November 1980: Louis Harris, *The ABC News—Harris Survey* (New York: The Chicago Tribune—New York News Syndicate, 1979-80); June 1979-October 1980 and December 1980: Edison Electric Institute surveys performed by Louis Harris and Associates (Washington, D.C.: Edison Electric Institute, 1979-80).

See figure 6-1.

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Appendix table 6-18. Proportions favoring or opposing the building of more nuclear power plants within five miles of their own communities, and in the United States generally: 1978-80

Date of survey	Near own community: Percent favor	Percent oppose	Percent not sure	In general: Percent favor	Percent oppose	Percent not sure	Sample size
September 1978[1]	35	56	9	57	31	12	1,556
(March 1979—Three Mile Island incident)							
September 7-8, 1979	37	59	4	50	40	10	1,200
September 21-23,1979	39	56	5	52	37	11	1,200
October 5-7,1979	36	59	5	44	45	11	1,200
October 19-21, 1979	36	59	5	45	43	12	1,197
November 2-4, 1979	33	62	5	42	47	11	1,199
November 16-18, 1979	34	62	4	48	42	10	1,197
November 30-December 2, 1979	36	59	5	49	41	10	1,494
December 14-16, 1979	38	58	4	48	40	12	1,195
December 27-30, 1979	39	57	4	48	39	13	1,516
January 10-13, 1980	41	54	5	51	37	12	1,498
January 24-27, 1980	33	62	4	50	39	11	1,196
February 7-10, 1980	35	60	5	50	40	10	1,197
February 21-24, 1980	35	61	4	45	44	11	1,196
April 17-20, 1980	34	63	3	47	46	7	1,198
July 25-27, 1980	35	60	4	48	40	12	1,203
September 7-11, 1980	35	62	4	49	42	9	1,193
October 11-13, 1980	38	58	4	52	39	9	1,200
December 1-8, 1980	37	60	3	50	40	10	1,200

[1]The wording of the "own community" question in September 1978 differed slightly from that used in the later surveys.

SOURCES: September 1978: Louis Harris, *The Harris Survey* (New York: The Chicago Tribune—New York News Syndicate, 1978). September 1979-December 1980: Edison Electric Institute surveys performed by Louis Harris and Associates (Washington, D.C.: Edison Electric Institute, 1979-80).

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Appendix table 6-19. Interest, level of information, and personal involvement regarding specific issue areas among attentives, nonattentives, and the total public: 1979

Issue area	Percent of		
	Attentives	Nonattentives	Total public
	(N=301)	(N=1,334)	(N=1,635)
Greatly interested in[1]			
Space exploration	34	10	15
Chemical food additives	46	29	32
Nuclear power plants	57	28	33
Well informed about[1]			
Space exploration	24	5	9
Chemical food additives	29	14	17
Nuclear power plants	39	12	17
Would definitely take an active part in controversies about			
Space exploration	12	6	7
Nuclear power plants	39	21	24

[1]Those who had not heard of controversies in these areas were assumed not to be interested or informed.

SOURCES: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U.S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), pp. 93, 104, 112; Jon D. Miller, unpublished data.

See table 6-13 in text.

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Appendix table 6-20. Proportion of public claiming to be informed about issue areas: 1979

Issue area	Percent		
	Very well informed	Moderately informed	Poorly informed
Foreign policy	8	54	37
Agriculture	10	44	45
New scientific discoveries	10	52	37
New inventions and technologies	10	50	39
Economics and business	14	55	31
Women's rights	17	53	30
Minority rights	18	53	29
Energy policy	18	58	23
Local schools	20	48	32

NOTE: Sample size was 1,635 for all items.

SOURCE: Koray Tanfer, Eugene Ericksen, and Lee Robeson, *National Survey of the Attitudes of the U.S. Public Toward Science and Technology.* Volume II: Detailed Findings (Philadelphia: Institute for Survey Research, Temple University, 1980), pp. 106-114.

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Appendix table 6-21. Comparative profile of attentives to science and technology: 1957 and 1979

Group	Percent of group found to be attentives		Percent of attentives who are in group		Sample size	
	1957	1979	1957	1979	1957	1979
All adults	8	19	100	100	1,919	1,472
By education:						
Less than high school	3	4	21	7	1,091	437
High-school diploma	13	11	57	19	678	467
Some college or college graduate	24	36	22	74	144	568
By sex:						
Female	6	13	44	37	1,091	776
Male	10	25	56	63	828	695
By age:						
21-34	9	26	36	48	584	508
35-54	8	17	47	31	853	492
55 and over	5	12	17	21	470	473

NOTE: The 1957 study was based on adults who were 21 years old and over, while the 1979 sample included 18-year-olds and over. Percentages from the source report were, therefore, recalculated to exclude the 18- to 20-year-olds in the 1979 sample.

SOURCE: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U. S. Public Toward Science and Technology* (Chicago: National Opinion Research Center, University of Chicago, 1980), p. 131.

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Appendix table 6-22. General reactions to science and technology in selected age groups: 1976-77

Age	Response, in percentages				
	Fear or alarm	Satisfaction or hope	Excitement or wonder	Indifference	No opinion
13	2	22	40	21	16
17	3	28	36	23	10
26-35	3	41	37	10	8

NOTE: Sample sizes not available.

SOURCE: *Attitudes Toward Science.* Report No. 08-S-02 (Denver: National Assessment of Educational Progress, Education Commission of the States, 1979), p. 26.

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Appendix table 6-23. Percentage of high-school and college students attentive to science, to technology, or to either science or technology: 1978

Group	Year in school	Attentive to science	Attentive to technology	Attentive to science or technology	Sample size
High-school students:					
Non-college-bound	10	0	3	3	466
	11	1	4	4	392
	12	1	7	7	358
College-bound	10	8	17	19	342
	11	9	16	17	361
	12	9	14	15	395
College students	13	18	21	23	254
	14	23	23	28	319
	15	23	27	31	386
	16	24	27	33	462

SOURCE: Jon D. Miller, Robert W. Suchner, and Alan M. Voelker, *Citizenship in an Age of Science: Changing Attitudes Among Young Adults* (New York: Pergamon, 1980), pp. 124-132.

See figure 6-2.

Science Indicators — 1980

Appendix II
Contributors and Reviewers

Contributors and Reviewers

Contributors[1]

The following individuals and organizations provided materials for use in the preparation of this report:

Jack Baranson, Developing World Industry and Technology, Inc.
Robert W. Campbell, Indiana University
Computer Horizons, Inc., Cherry Hill, N.J.
Division of Productivity Research, U.S. Bureau of Labor Statistics
Thomas D. Duchesneau, University of Maine
Irwin Feller, Pennsylvania State University
The Futures Group, Glastonbury, Conn.
Herbert S. Gutowsky, University of Illinois
George R. Heaton, Jr., Massachusetts Institute of Technology
Christopher T. Hill, Massachusetts Institute of Technology
Institute for Survey Research, Temple University
Irene Kiefer, Bethesda, Md.
Franklin A. Long, Cornell University
John O. Ludwigson, Washington, D.C.
Edwin Mansfield, University of Pennsylvania
L. John Martin, University of Maryland
Joseph L. McCarthy, University of Washington
National Opinion Research Center, University of Chicago
Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office
W. Curtiss Priest, Massachusetts Institute of Technology
Nat C. Robertson, Princeton, N.J.
Nathan Rosenberg, Stanford University
Francis W. Rushing, SRI International
Willis H. Shapley, American Association for the Advancement of Science
Raymond Vernon, Harvard University
Harold Wool, Bethesda, Md.

Reviewers

The following individuals reviewed single chapters or portions of chapters:

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Kenneth Arrow, Stanford University
John D. Baldeschwieler, California Institute of Technology
Robert Bock, University of Wisconsin—Madison
Donald D. Brown, Carnegie Institution
Donald Collier, Borg-Warner Corp.
William Comanor, University of California—Santa Barbara
William N. Cooke, Cornell University
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Saville Davis, *Christian Science Monitor*
Herbert I. Fusfeld, New York University
E. M. (Monty) Graham, Organisation for Economic Co-operation and Development, Paris, France
Zvi Griliches, Harvard University
W. Lee Hansen, University of Wisconsin—Madison
Gary C. Hufbauer, Georgetown Law Institute
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D. Bruce Merrifield, The Continental Group
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Daniel Zaffarano, Iowa State University

[1] Information on the availability of material provided by these individuals and organizations is available from Science Indicators Unit, Division of Science Resources Studies, National Science Foundation, 1800 G Street, N.W., Washington, D.C. 20550.

Index of Data for Selected Policy Issues

Index of Data for Selected Policy Issues

This index indicates where in each chapter information can be found to illuminate selected policy issues.

International Science and Technology

Resources for Research and Development

Resources for Basic Research

Industrial R&D and Technological Performance

Scientific and Engineering Personnel

Subject and Author Index

Subject and Author Index

Cut along broken line and fold

USER SURVEY

The judgments and inputs of users of this report are valuable elements for the planning of *Science Indicators—1982*. In addition to providing responses to the following questions, users are encouraged to communicate further with the Science Indicators Unit of the National Science Foundation.

1. How do you think you will use this report?
(check all that apply)

_____ Monitoring trends
_____ Instructional material
_____ Developing legislation
_____ General information source
_____ Projecting or forecasting
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2. What do you see as the strengths and weaknesses of this report, compared to similar reports?
(check all that apply)

Strengths	*Item*	*Weak-nesses*
_____	Breadth of content	_____
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_____	Summaries and overviews	_____
_____	Topical/author index	_____
_____	Index of data for selected policy issues	_____
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_____	Statistical tables	_____
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	Other: _____________________	

3. Please elaborate on the weaknesses checked in Item 2 and other areas of improvement.

4. Which indicators or interpretations are the best overall indicators of science and technology?

5. Which indicators or interpretatons:
a. are or will be of most use to you in your work?

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6. What is your employment sector?
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_____ Federal Government
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